2013

Temporal and spatial variations in the subsurface salinity of Lake Charles, Louisiana : an investigation of saline sources

Alexandria Suding
Louisiana State University and Agricultural and Mechanical College

TEMPORAL AND SPATIAL VARIATIONS IN THE SUBSURFACE SALINITY OF LAKE CHARLES, LOUISIANA: AN INVESTIGATION OF SALINE SOURCES

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Geology

by
Alexandria M. Suding
B.S., University of Notre Dame, 2011
August 2013

I dedicate this thesis to the late Dr. J.K. Rigby, Jr. I will never forget your strange, but memorable geology anecdotes!

ACKNOWLEDGMENTS

I would like to thank John and Wendy Lovelace for providing me with USGS water quality data. Also, thank you to Riley Milner for helpful advice and assistance in obtaining LADOTD well logs. Thank you to Dr. Jeffrey Hanor for the use of his SP to salinity spreadsheet, as well as all of his well log guidance along the way. Thank you to previous graduate students whose work has provided a knowledge base and an example to me, especially Callie Anderson.

The graduate committee for this project included Dr. Clinton Willson from the Department of Civil Engineering, Dr. Phil Bart from the Department of Geology and Geophysics, and my committee chair Dr. Carol Wicks from the Department of Geology and Geophysics. I am very appreciative each of your unique contributions and suggestions.

Finally, I want to express many thanks to my family and friends for their support and encouragement throughout this entire process.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

One of the most pressing issues facing groundwater managers is saltwater intrusion. In coastal Louisiana this issue is especially prevalent. One location that is currently threated by saltwater intrusion is the industrial area of Lake Charles, Louisiana, where three high chloride areas have been detected within the underlying Chicot aquifer. Three sand units of the Chicot aquifer are present in Lake Charles: the 200-foot (200') sand, the 500' sand, and the 700' sand. Groundwater with elevated chloride concentrations was first noticed by industries in the early 1970s. An initial investigation determined that the northern and southern bodies had formed by upwelling of saline groundwater from the 700' sand. However, the origin of the salinity in the central body was not determined. The objective of this study was to determine the origin of the salinity for the central chloride body. Two sources of data were obtained from wells in the area: (1) spontaneous potential (SP) and resistivity logs from oil and gas and water wells (2) water quality data from United States Geological Survey (USGS) monitoring wells. The result of this study was the creation of a series of isoconcentration contour maps that help illustrate the movement of the saline groundwater in each aquifer layer over time. Results indicate that saline groundwater has been introduced into the aquifer from a variety of sources over time, including surficial contamination and upwelling of brine from the Lockport salt dome.

INTRODUCTION

One of the most pressing issues threatening groundwater quality is the intrusion of saline water into freshwater aquifers (Tomaszewski, 1996; Barlow & Reichard, 2010; Welch & Hanor, 2011). Protecting groundwater from saline intrusion is important because once saltwater enters an aquifer, it is often difficult to reclaim that aquifer (Nyman, 1984). It is especially important to protect groundwater supplies that are the sole-source of drinking water for an area. A sole-source aquifer means that the aquifer supplies at least half of the drinking water for the area (USEPA, 2013). In coastal Louisiana, groundwater is at risk of saline water intrusion due to high rates of groundwater pumping and due to the existence of subsurface salt domes that may act as a source of saline water.

This study is focused on the Chicot aquifer that serves as a sole-source water supply for most of southwestern Louisiana (Figure 1.1). One of the largest cities supplied by the Chicot aquifer is Lake Charles in Calcasieu Parish, Louisiana (Figure 1.2). In the Lake Charles area, the principle freshwater bearing sands of the Chicot aquifer are referred to as the “200-foot,” “500-foot,” and “700-foot” sands. All of these aquifers are utilized in Lake Charles, with the 500’ being the most heavily pumped (Lovelace, 1998). In recent history, Lake Charles has experienced saline water intrusion due to excessive groundwater pumping (Nyman, 1984).

Groundwater pumping in Calcasieu Parish has decreased from past rates (Figure 1.3). Still, in 2010, 86.65 million gallons per day (Mgal/day) were withdrawn from the Chicot aquifer system, making Calcasieu Parish one of the top groundwater consumers in the state. The majority of this water was used for industry (40.88 Mgal/day) and public supply (25.73 Mgal/day) (Sargent, 2010). Lake Charles is a major center for both industry and population in Calcasieu Parish; thus, groundwater is pumped extensively. Figures 1.4-1.6 display the

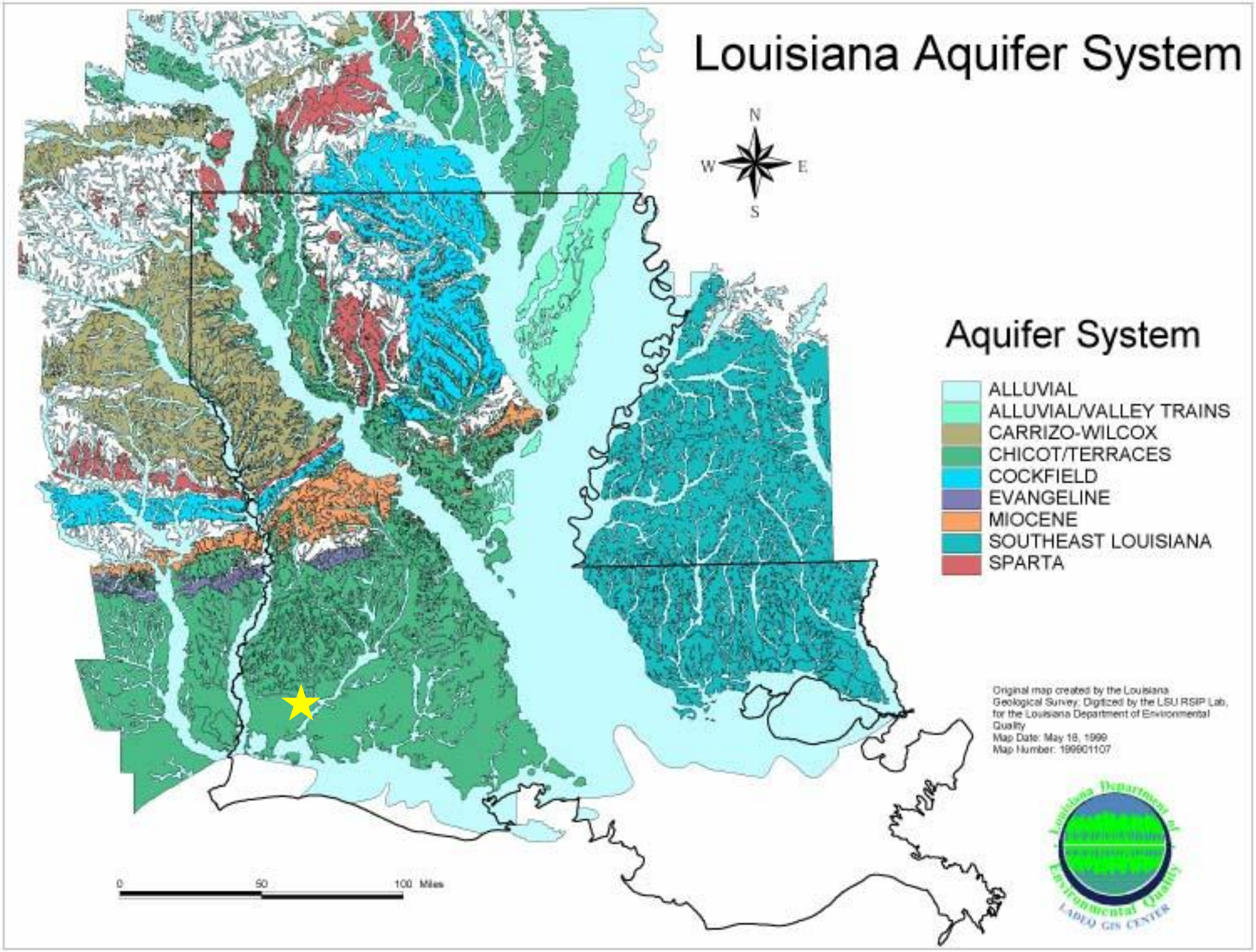

Figure 1.1. Map showing the locations of the aquifers of Louisiana. The Chicot aquifer covers the majority of southwestern Louisiana. The yellow star denotes the approximate location of the study area. Modified from: LDNR GIS Center (1999).

Figure 1.2. Location of Lake Charles, within Calcasieu Parish, LA. Source: Figure was created using LDNR SONRIS (2012).

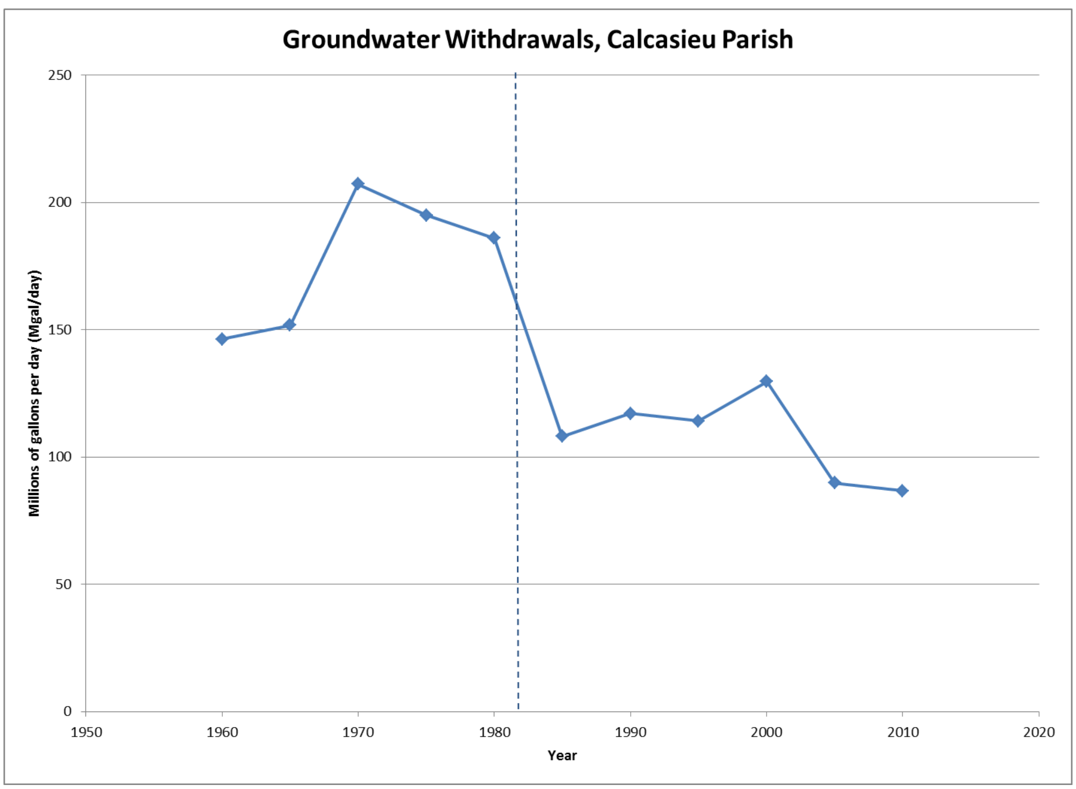

Figure 1.3. Total groundwater withdrawals in Calcasieu Parish from 1960-2010. Dashed line indicates the opening of the Sabine River Diversion Canal. Source: Water Use Reports, 1960-2010, DOTD).

locations of pumping wells in the Lake Charles industrial district from the 1940s to the 1990s. Intense pumping of these wells over several decades has created a cone of depression under the Lake Charles industrial district (Lovelace, 1998). This cone of depression is an exacerbation of a regional cone of depression that exists due to rice farming and irrigation in the agricultural areas surrounding Lake Charles (Figure 1.7).

High rates of groundwater pumping in the Lake Charles area has caused aquifer water levels to decline in all of the freshwater aquifer sands, causing saline water in the subsurface to move toward the pumping areas (Lovelace, 1998). Water quality degradation has been noted. In 1972, industries in Lake Charles became concerned about the increasingly saline groundwater (Nyman, 1984). Investigations at the time identified three areas of groundwater within the 500' sand with high chloride values (Figure 1.8). These areas have chloride concentrations that are well above the background chloride concentration of about 30 mg/L (Nyman, 1984). Two of the high chloride areas are located in areas where the 500' sand is heavily pumped. Extensive pumping likely caused upwelling of saline water from depth (Nyman, 1984; Lovelace, 1999). The source of saline water for the third area is unknown. This area is not located near pumping wells; thus, upwelling of saline water due to pumping seems unlikely.

Efforts have been made in the past to mitigate excessive pumping and saltwater intrusion. The extensive usage of groundwater from the Chicot aquifer was reduced dramatically in 1982 by the opening of the Sabine River Diversion Canal. This canal was dug to provide fresh surface water to the Lake Charles area and reduce pumping of groundwater by industry (Lovelace, 1998). Though the diversion canal was helpful in raising aquifer water levels (Figure 1.9), saline encroachment has continued to be an issue.

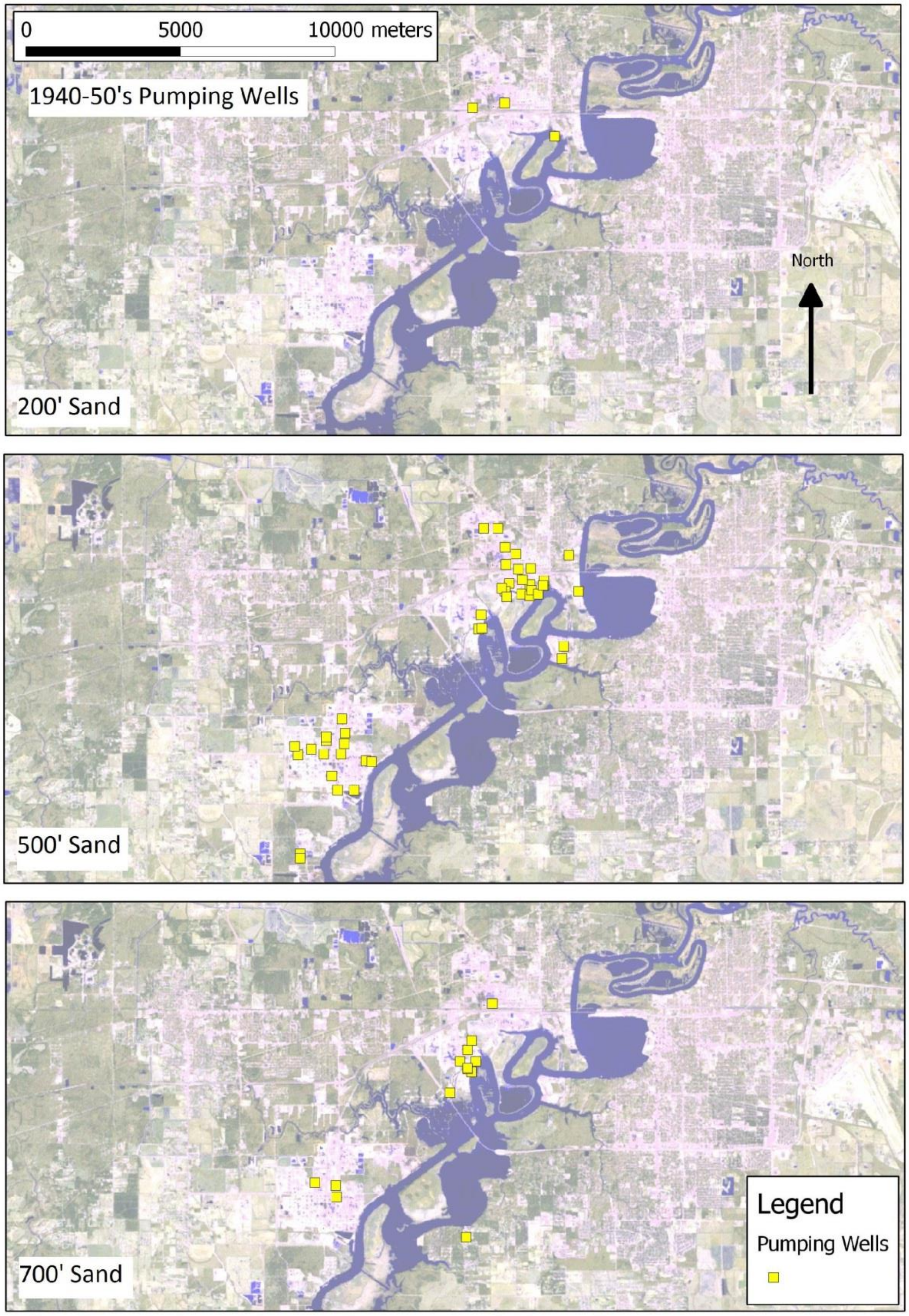

Figure 1.4. Locations of pumping wells during the 1940-50s in the Lake Charles Industrial Area. The top panel displays the wells screened in the 200’ sand, the middle screen shows the wells screened in the 500’ sand, and the bottom panel shows the wells screened in the 700’ sand. The figure was created using QGIS (2013).

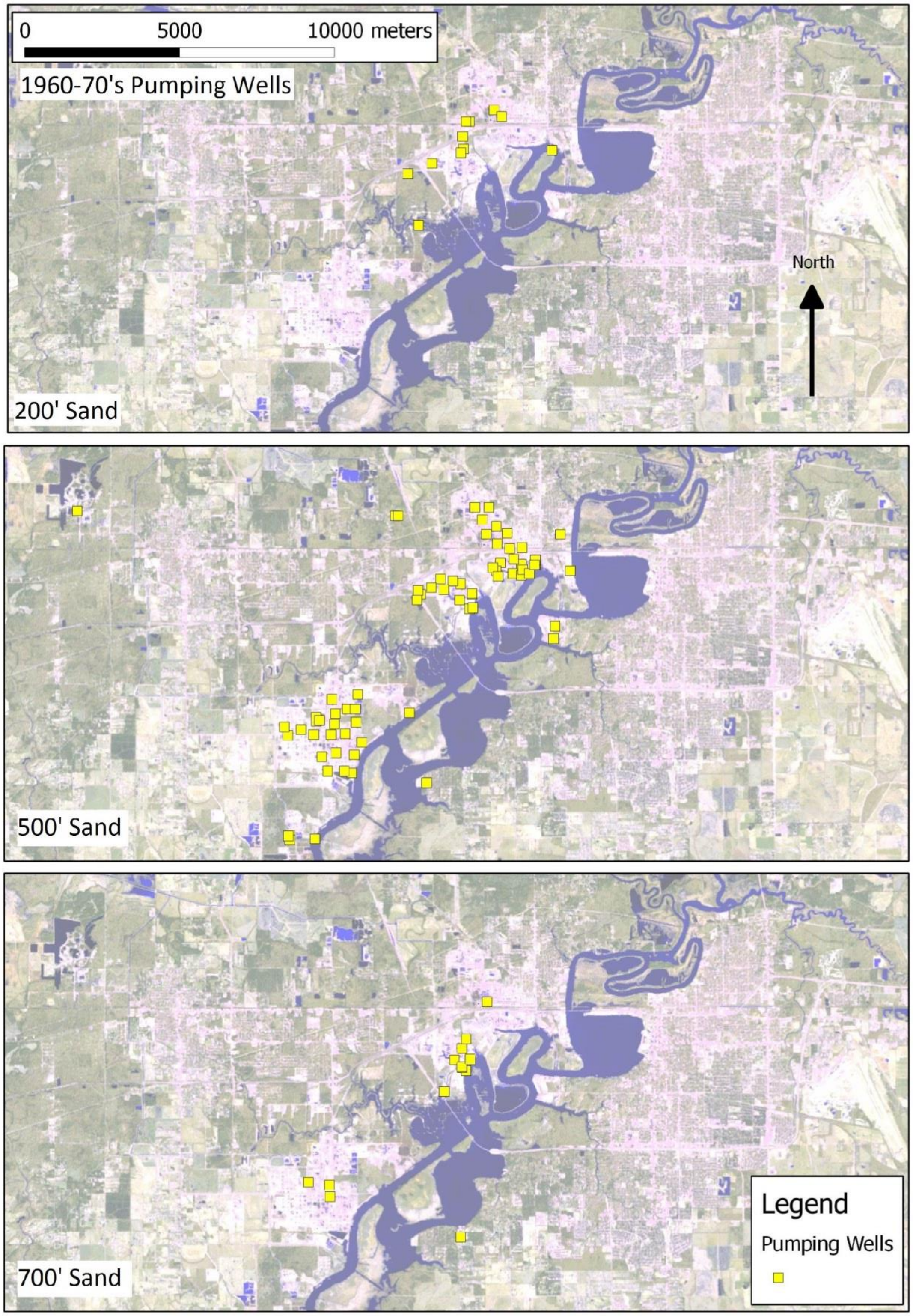

Figure 1.5. Locations of pumping wells during the 1960-70s in the Lake Charles Industrial Area. The top panel displays the wells screened in the 200’ sand, the middle screen shows the wells screened in the 500’ sand, and the bottom panel shows the wells screened in the 700’ sand. The figure was created using QGIS (2013).

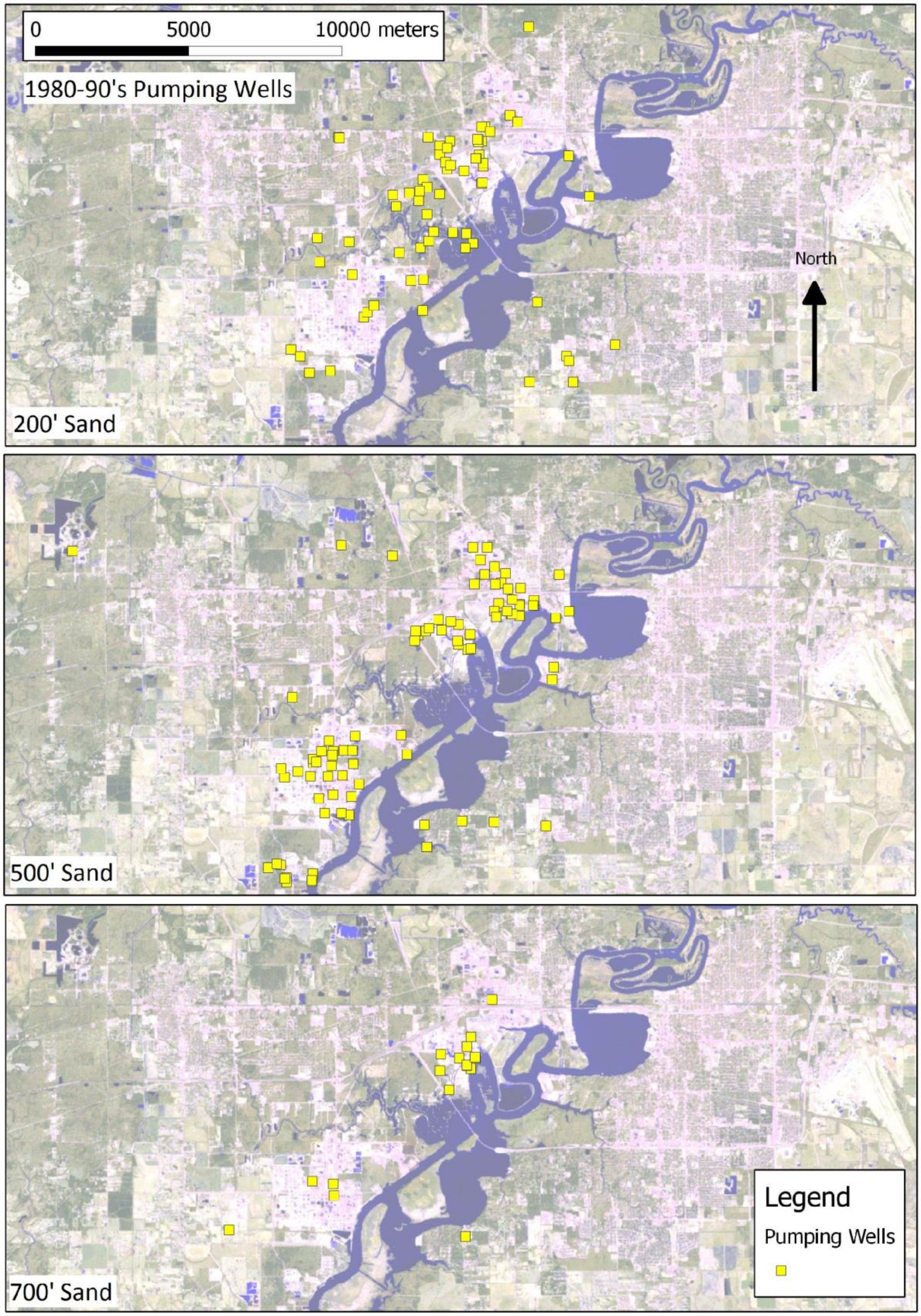

Figure 1.6. Locations of pumping wells during the 1980-90s in the Lake Charles Industrial Area. The top panel displays the wells screened in the 200' sand, the middle screen shows the wells screened in the 500' sand, and the bottom panel shows the wells screened in the 700' sand. The figure was created using QGIS (2013).

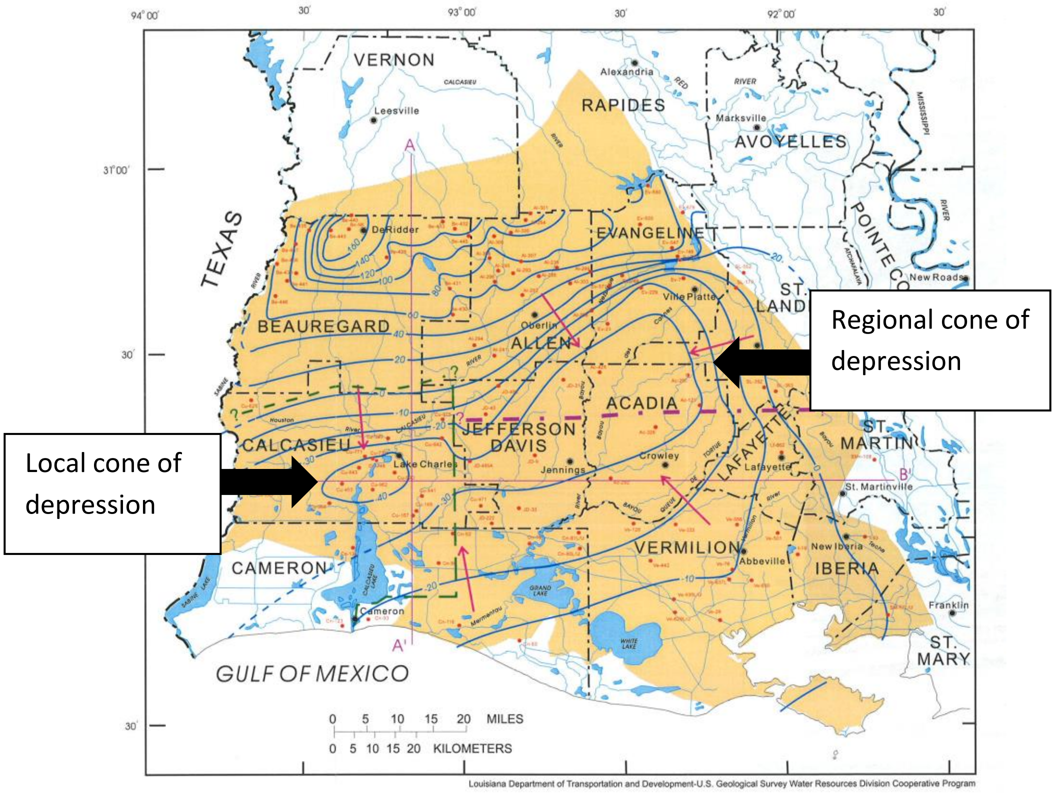

Figure 1.7. Map showing the regional cone of depression that developed in the Chicot aquifer due to the extensive use of groundwater for rice irrigation, as well as the local cone of depression under Lake Charles. Source: Modified from Lovelace (1998).

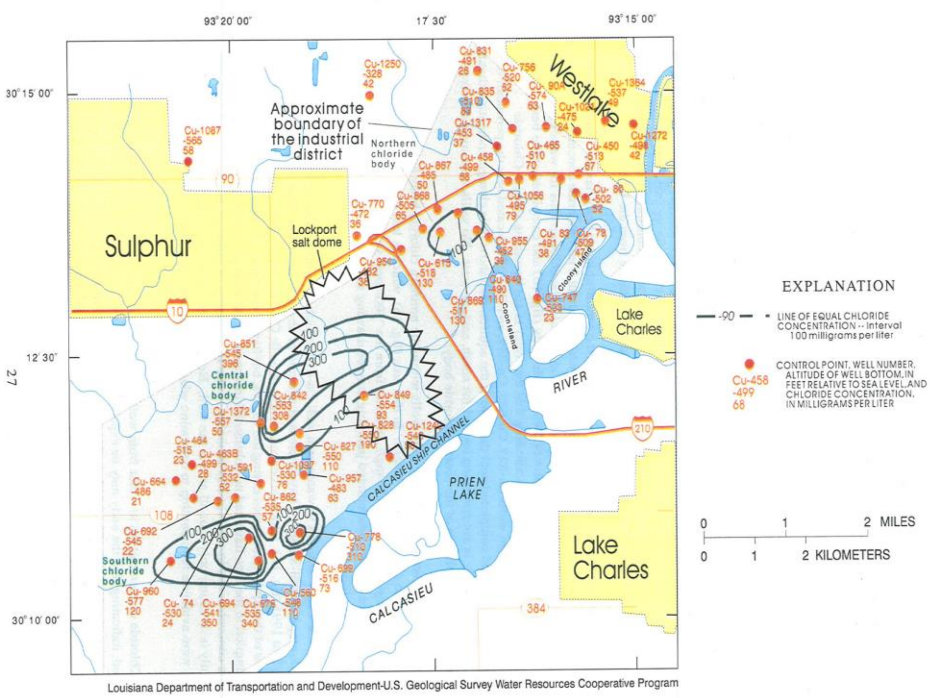

Figure 1.8. Map showing the location of the three high chloride bodies in the 500' sand of the Lake Charles industrial district. Source: Lovelace (1998).

Screened in 200' sand of Lake Charles Area:

Screened in 500' sand of Lake Charles Area:

Screened in 700' sand of Lake Charles Area:

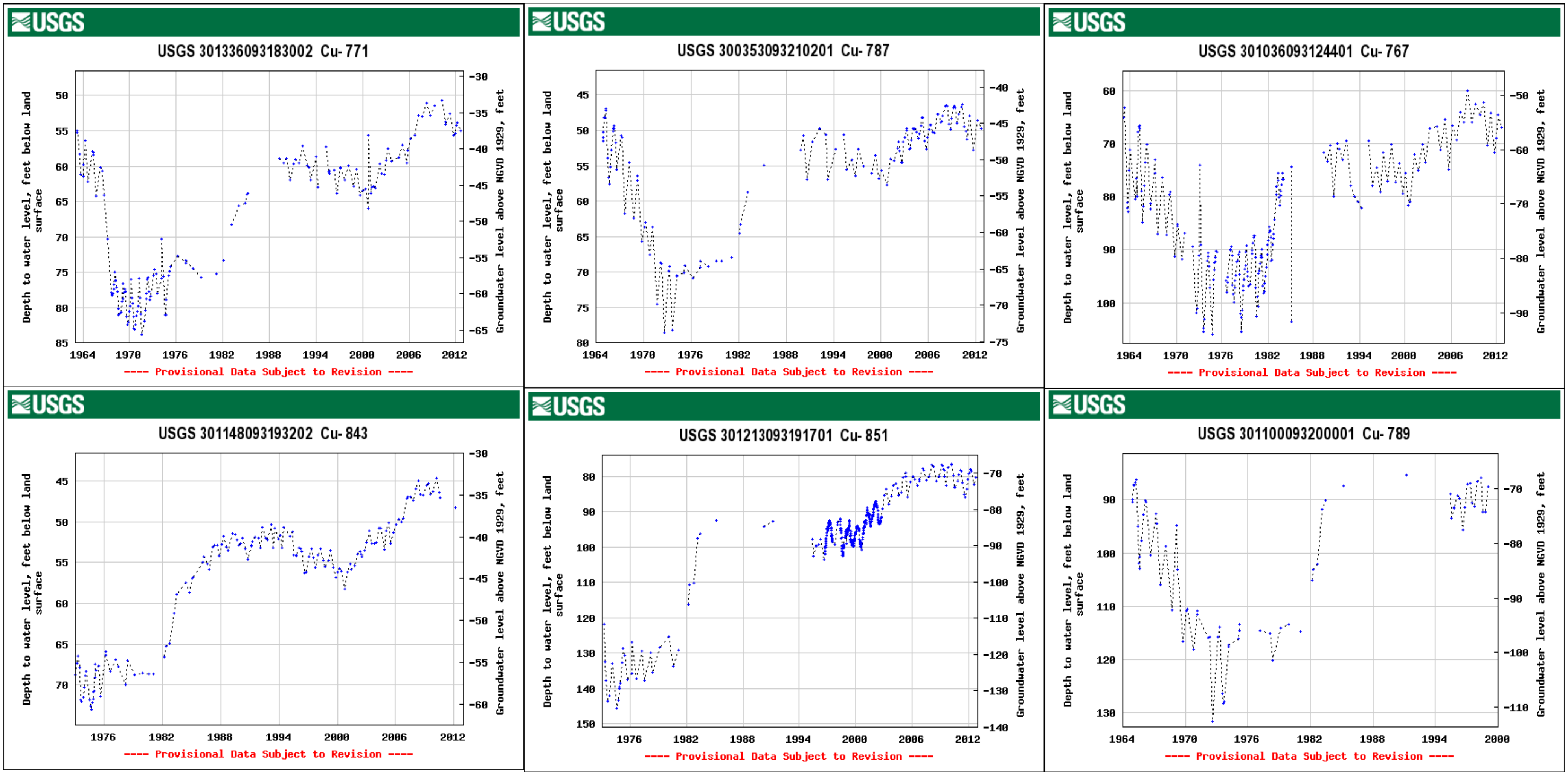

Figure 1.9. Groundwater level data from six USGS wells in the Lake Charles area. Note that groundwater level in all wells increases around the 1982 opening of the Sabine River Diversion Canal. Source: USGS Lousiana Water Science Center (2013).

The objective of this study is to determine the source of salinity in the central saline body in the Lake Charles Industrial district. Potential sources of salinity include upwelling of marine saline water, dissolution of a nearby salt dome, upwelling of formation waters, or chloride contamination from oil and gas operations or industry. By using well logs in the area, maps of subsurface salinity will be created to show where plumes of salinity originate. The magnitude of the salinity in the plumes will also provide information about their source; for example, dissolution of salt domes would create a much higher salinity than upwelling of formation waters.

The determination of the salinity source in the Lake Charles industrial district is important because the Lake Charles industry, as well as the public, rely on freshwater from the Chicot Aquifer. As this aquifer is a sole-source aquifer, it is vitally important to protect the groundwater quality. If this study can help to pinpoint where the saline groundwater is originating, then efforts can be made to abate the movement of this high chloride groundwater into pumping areas.

GEOLOGIC SETTING

General Geology

Lake Charles is located in east-central Calcasieu Parish along the Calcasieu River. Calcasieu Parish is bounded on the north by Beauregard Parish, on the east by Jefferson Davis Parish, on the south by Cameron Parish, and on the west by Orange and Newton Counties of Texas. The study area lies within the West Gulf Coastal Plain and is an area of low relief, with altitudes ranging from around 2 feet to 90 feet above sea level (Harder, 1960).

Surficial geology of the area consists of the Prairie Formation (Harder, 1960). This formation is related to periods of Pleistocene glaciation and melting, which produced transport and sedimentation along rivers and in coastal deltas of Louisiana during coastline shifts. Sand units were deposited as flood plain and delta deposits, whereas clay units were flood plain and lagoonal deposits (Nyman, 1984). Underlying geology consists of additional coastal sediments of Quaternary and Tertiary age (Harder, 1960).

The Chicot & Evangeline Aquifer Systems

The Chicot aquifer system contains unconsolidated sedimentary deposits of Pleistocene age. The aquifer layers contain gravel, sand and silt that generally have a fining upward sequence (Harder, 1960). Regionally, aquifer units dip about 20 ft/mi to the southeast (Milner & Van Biersel, 2006). The units thicken as they approach the Gulf of Mexico, but they also become finer grained and more subdivided by clay layers (Nyman, 1984). As previously mentioned, in Lake Charles, the aquifer units are referred to as the 200’, 500’, and 700’ sands. The 200’ sand is typically less than 100 feet thick, but it can be up to 200 feet thick; the 500’ sand ranges from 170-200 feet thick; the 700’ sand is approximately 220 feet thick (Nyman et.

al., 1990). These large sands were likely deposited as transgressive sequences during periods of glacial melting and sea-level rise due to the fact that the sand layers have a fining upward grain size distribution. In addition to the main aquifer layers, numerous shallow lenses of sand exist within the overlying confining clay unit and act as small, perched aquifers (Lovelace, 1999).

The 200', 500', and 700' sand layers of the Chicot aquifer are interconnected and undifferentiated just to the northeast of Calcasieu Parish; here, the aquifer unit is referred to as the 'massive sand'. To the east, the 500' sand unit combines with the 700' sand, becoming the 'lower' sand; the 200' sand is referred to as the 'upper' sand (Lovelace, 1998). Farther toward the east, the Chicot aquifer system connects with Atchafalaya and Mississippi River alluvium (Figure 2.1) (Lovelace, 1998). In all locations, the base of the 700' (or lower) sand is considered to be the base of the Chicot aquifer (Harder, 1960).

The Chicot aquifer is underlain by the Evangeline aquifer of Pliocene and Miocene age. The top of the Evangeline aquifer is encountered at a depth of approximately 850 feet in the Lake Charles area. The base of the Chicot and the top of the Evangeline can be difficult to distinguish, as they both contain similar sedimentary deposits (Harder, 1960). In most areas, the aquifer systems are separated by a thin clay bed, but sometimes they directly connect (Milner & Van Biersel, 2006). The Evangeline system consists of fine to medium sand, silt, and clay (Harder, 1960). The aquifer is approximately 2000 feet thick in the Lake Charles industrial area (Harder, 1960), with individual sand bed thicknesses that are highly variable and often laterally discontinuous (Lovelace, 1999). Near the city of DeQuincy (located near the northern boundary of Calcasieu Parish), the aquifer is about 650 feet deep and contains freshwater (Harder, 1960). There, and in other parishes directly north of Calcasieu Parish, the Evangeline aquifer is used as

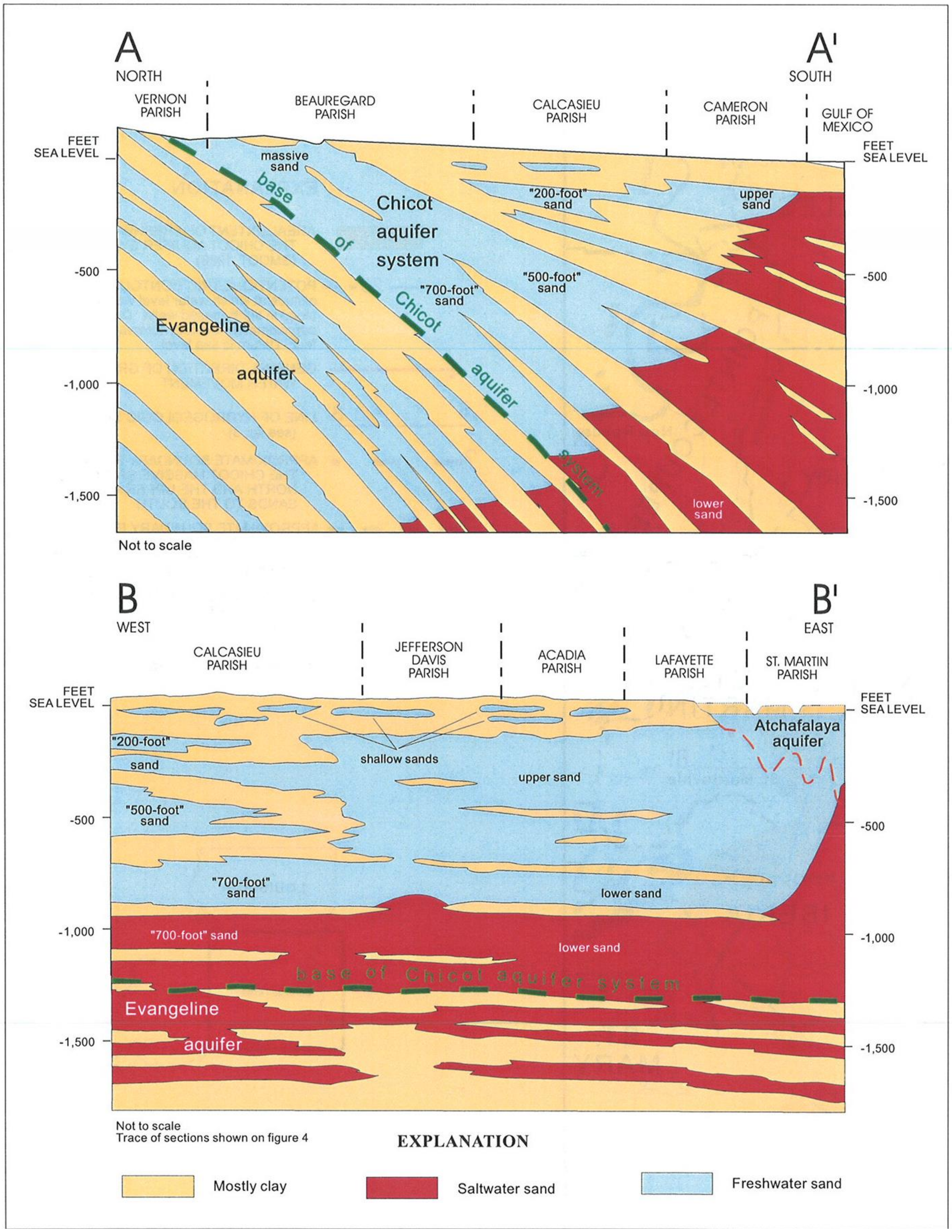

Figure 2.1. Regional cross-sections illustrating the changes in the thickness and interconnectedness of the sand units of the Chicot aquifer. Source: Nyman (1984) modified by Lovelace (1998).

a source of freshwater. However, the depth and salinity (>10,000 ppm total dissolved solids) of the Evangeline aquifer in the Lake Charles area makes it unusable as a freshwater source.

Recharge to the Chicot aquifer occurs mostly by downward percolation of freshwater into the outcrop areas north of Calcasieu Parish (Lovelace, 1998). Another source of freshwater recharge is from the Atchafalaya Aquifer to the east. Freshwater is also able to infiltrate through the surficial confining clay unit, as the vertical hydraulic conductivity of the clay in the Chicot Aquifer has been increased by weathering and faulting. Finally, in some areas, upwelling from the underlying Evangeline aquifer can also be a source of saline recharge (Lovelace, 1999).

Salt Domes

A common geologic feature in the southern Louisiana area is the salt dome. In the upper Jurassic, a thick layer of salt, called the Louann Formation, was deposited in the newly-opening Gulf of Mexico. The salt was formed from the influx and subsequent evaporation of seawater within the shallow, extensional basin (Bird et. al., 2005). Subsequent deposition of sediment into the Gulf of Mexico basin covered the salt layer, and as the sediment compacted, its density was increased. The increased density of the overlying material caused the salt to plastically flow into structures, such as domes (Halbouty, 1979), which are now scattered throughout the South Louisiana subsurface. There are six large salt domes in Calcasieu Parish: the Edgerly, Lockport, North Starks, Starks, Sulphur, and Vinton (Halbouty, 1979). The dome closest to Lake Charles is the Lockport dome, which is located under the industrial area of the city. Figure 2.2 shows the locations of salt domes in Calcasieu Parish. There is no clear consensus on the exact locations and dimensions of each salt dome, as geologists have interpreted seismic data in slightly different ways (Beckman & Williamson, 1990).

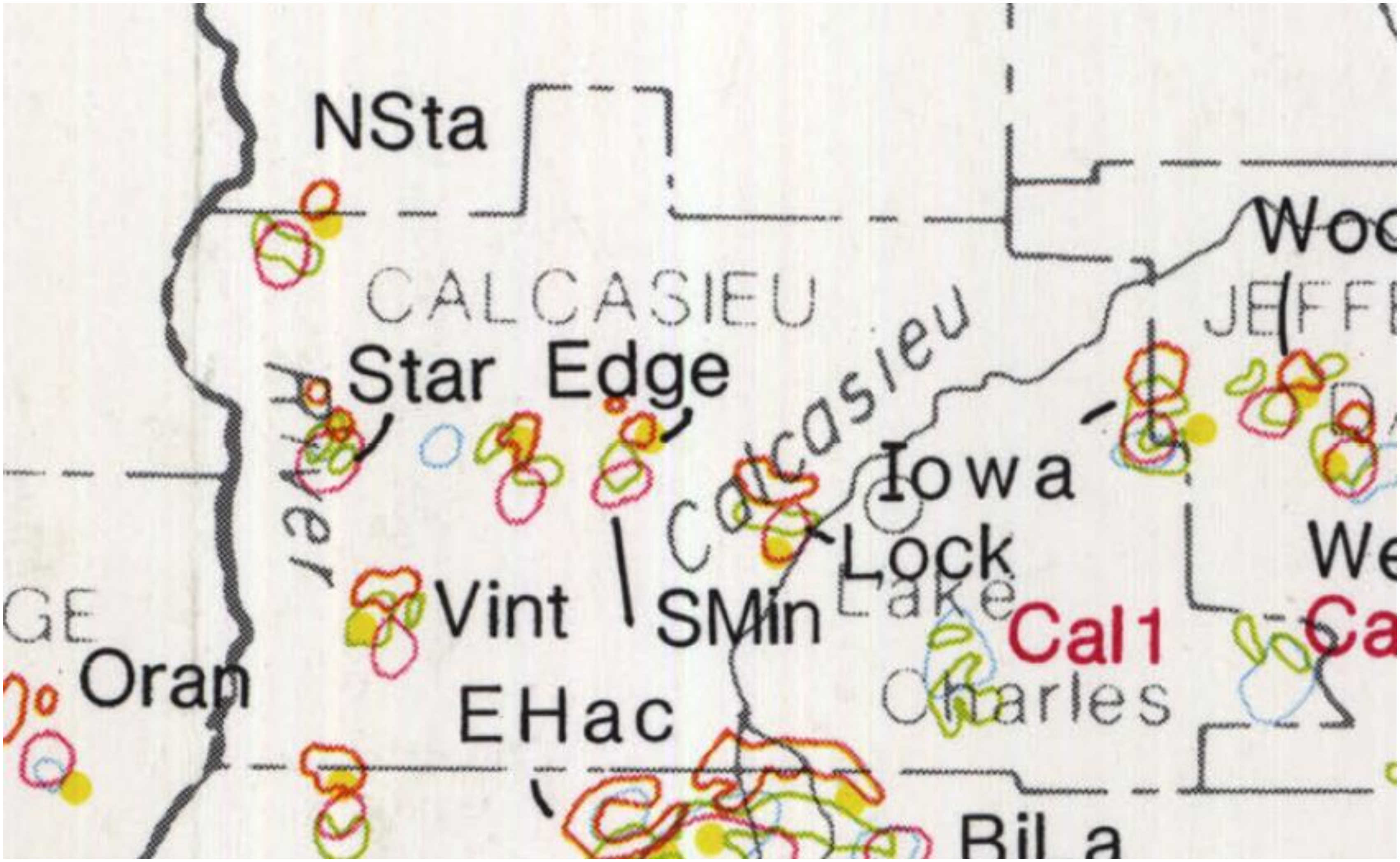

Figure 2.2. Interpreted locations of salt domes in Calcasieu Parish. Study area is in the vicinity of the Lockport salt dome, indicated by 'Lock' on this figure. Edge = Edgerly, Lock = Lockport, NSta = North Starks, Star = Starks, SMin = Sulphur (Mines), and Vint = Vinton. Different colored outlines represent different authors' interpretations. Modified from: Beckman & Williamson (1990).

The Lockport dome was discovered in 1922 when gas seeps were noticed in a nearby marsh (Halbouty, 1979). The dome is classified as an intermediate depth salt dome with the top of salt encountered at 8,160 feet deep (Halbouty, 1979). Lockport dome is part of a large, east-west trending salt ridge that includes several other salt domes in the area (Wallace, 1944).

Formation of the Lockport dome created an oil and gas trap, which has been drilled and produced since 1924. Lockport oil field has produced over 30 million barrels of oil and over 25,000 million cubic feet (MMcf) of gas (Halbouty, 1979). This oil and gas production activity may have contributed to the elevated salinity in the area (Lovelace, 1998), as subsurface brines are a byproduct of oil and gas production. In the past, these brines were not always disposed of properly; brines were typically placed in unlined well pits and allowed to permeate back into the ground. Alternatively, dissolution of the salt dome itself may be the cause for salinity increases in the area. However, as the dome is quite deep, movement of saline water would have to travel vertically along faults near the salt dome in order to reach the shallow aquifer units.

Faults

A comprehensive description of faults in South Louisiana or Calcasieu Parish does not exist. However, the presence of faults in the vicinity of the Lockport salt dome has been noted in the past. In the 1960s, the USGS was commissioned to study methane gas in the groundwater of Lake Charles. Part of this investigation involved describing the stratigraphy and structural features of the area. The results of the study indicated a large graben structure above the Lockport salt dome, with normal faults extending up to the 700' sand (Hodges et. al., 1963). Within the large graben, they interpreted an area with numerous minor faults. Figure 2.3 shows the stratigraphic and structural interpretation from this study. Graben-type fault structures are commonly found above salt domes in South Louisiana (Wallace, 1944).

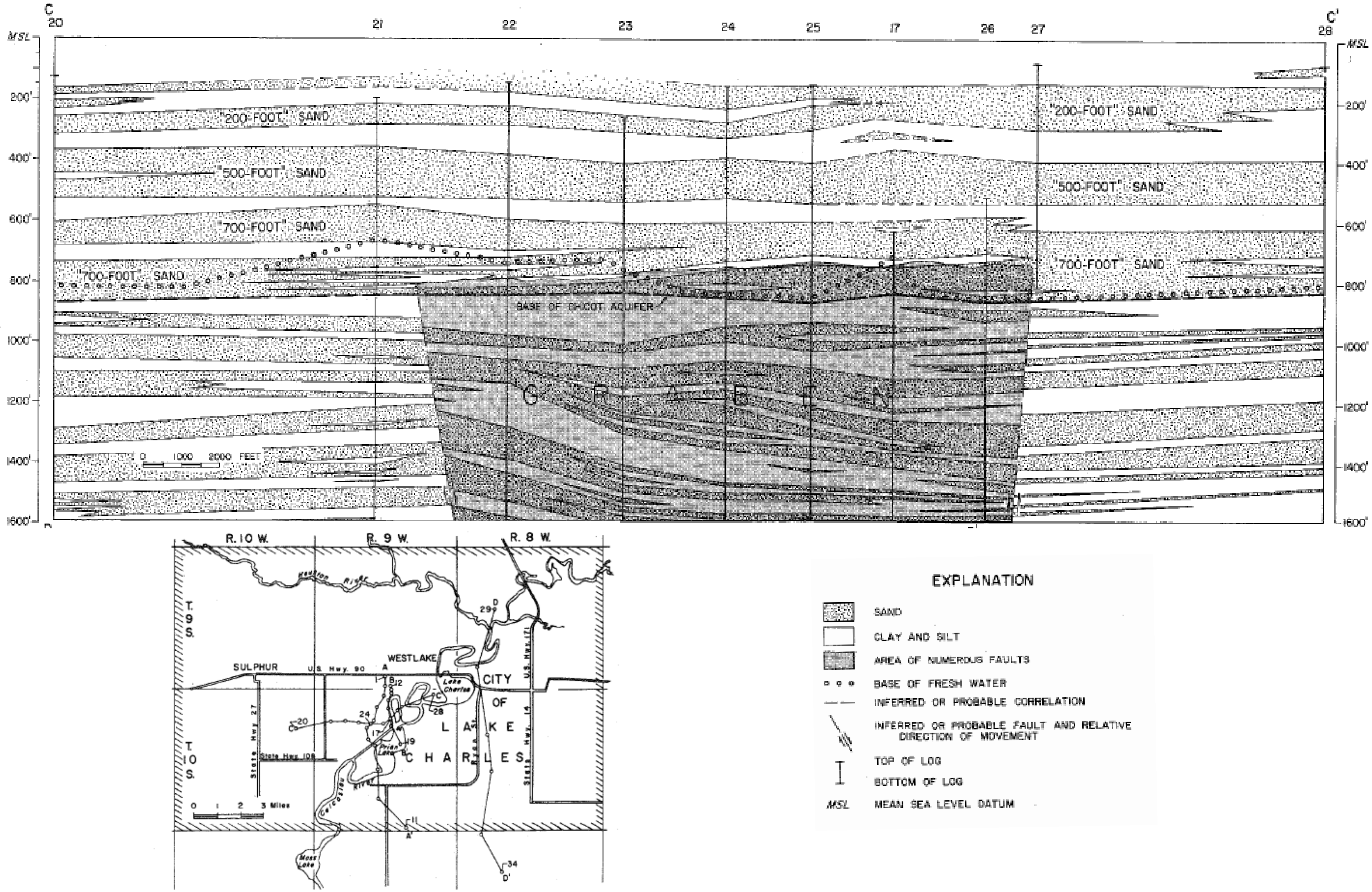

Figure 2.3. Stratigraphic and structural cross section C – C' through the Lake Charles industrial area. This interpretation shows a graben structure above the Lockport salt dome. Modified from: Hodges et. al. (1963).

Overpressured Zone

Overpressured zones are areas of high pressure located within the subsurface. In Louisiana, these zones are believed to have been caused by rapid deposition and burial of sediment within the Gulf of Mexico basin during recent geologic history. When rapid burial occurs, saturated sediment gets compacted, which increases pore pressure. The area of increased pore pressure is referred to as the overpressured zone because the pressure is higher than a normal hydrostatic gradient would predict. Overpressured zones can influence groundwater movement, as groundwater wants to escape the zone and move upward to lower pressure areas (Ingebritsen et. al., 2006).

By using drilling mud weight as a proxy, it was possible to roughly calculate subsurface pore pressures in the study area. The pressure, in pounds per square inch (psi), was calculated by multiplying the mud weight (in pounds per gallon) by a conversion factor of 0.052 (Hanor, 1987). After obtaining oil and gas well log headers with several different run depths and mud densities, a pressure vs. depth curve was created for the central area of the Lake Charles industrial district (Figure 2.4). This graph shows an apparent overpressure zone at a depth of approximately 8,500 feet. Here, the pore pressure increases dramatically and deviates from a normal hydrostatic gradient.

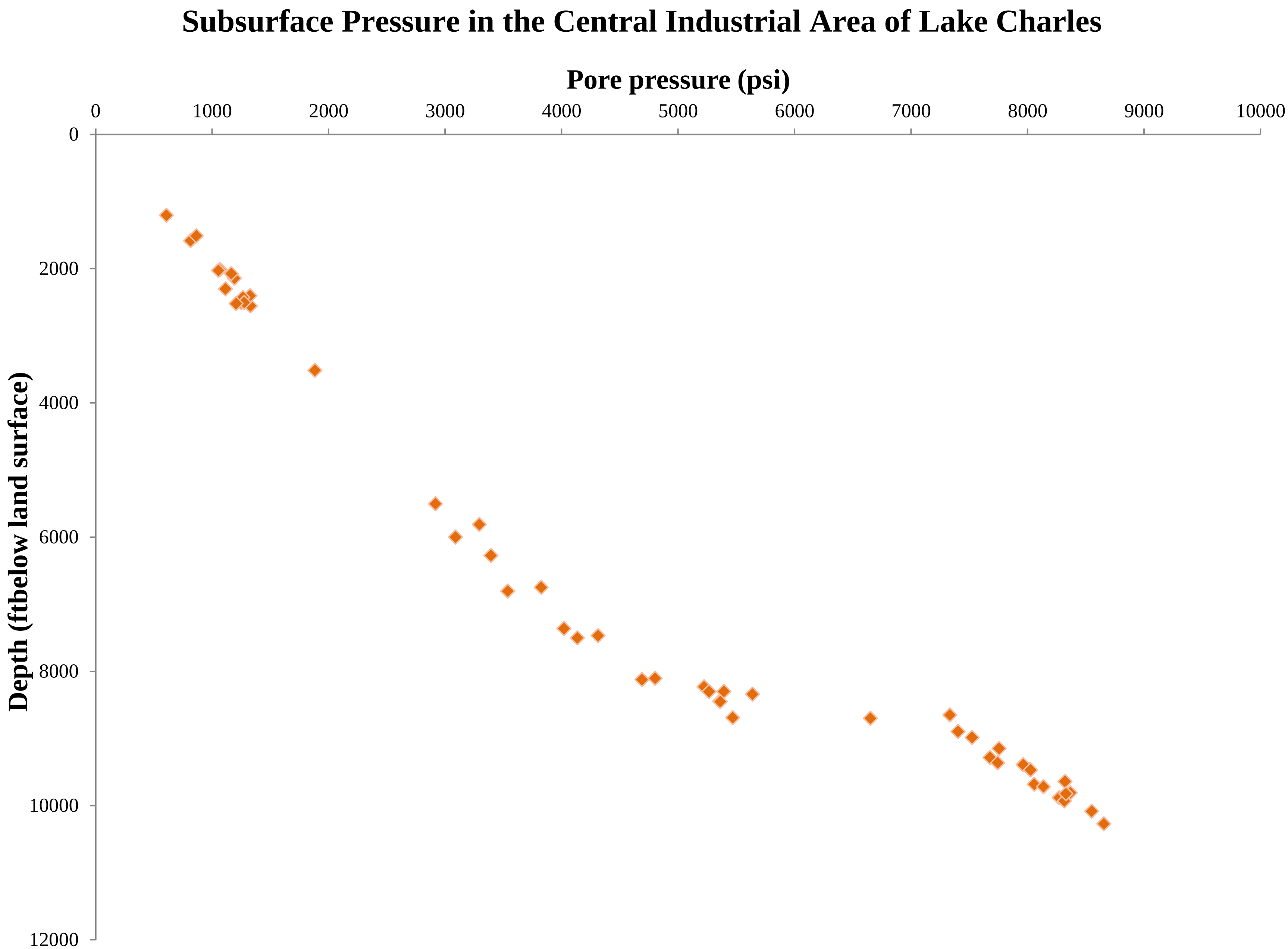

Figure 2.4. Plot showing pore pressure versus depth in the central area of the Lake Charles industrial district. Pressure values were calculated using oil and gas well drilling mud weights. Note the overpressured zone at ~8,500 feet deep.

METHODS

Introduction

The general approach to this study was to utilize oil and gas well logs to determine subsurface salinity in the industrial area of Lake Charles. Wireline spontaneous potential (SP) and resistivity logs were used. For shallow intervals (<900 feet), resistivity logs were used, as these are better for determination of low salinity values (Anderson & Hanor, personal communication). SP logs were used to determine salinity at depths greater than 900 feet. Determination of the subsurface salinity allowed for the creation of contour maps of salinity plumes at varying depths at varying times. This information has provided insight into the source of the elevated salinity and the path along which it has flowed. This method is based on previous studies that have had success in determining subsurface salinity plumes based on well log data (Bennett & Hanor, 1987; Funayama & Hanor, 1995; Anderson, 2011; Welch & Hanor, 2011).

Selection of well logs

The majority of the well logs used for this study were obtained from the Louisiana Department of Natural Resources (LDNR) SONRIS database. All available oil and gas wells in the Lake Charles industrial area were identified. Those wells without electrical logs were immediately eliminated. The rest of the wells were then evaluated based on the depths logged, the proximity to other wells, and the file quality and legibility. Well logs were obtained from the 1940s to the 1980s. The wells from the 1940s and 1950s have long normal resistivity logs, whereas the logs from the 1960s to 1980s contain 40-inch induction resistivity logs.

Additional well logs were obtained from the Louisiana Department of Transportation and Development (LADOTD) water well database (Milner, personal communication). These well logs only cover shallow depths, and thus were only evaluated for resistivity. All of these wells contain long normal resistivity logs.

In total, seventy-six viable well logs were chosen throughout the Lake Charles industrial area. The selected wells were separated according to year to allow for study of salinity changes in the area through time. Time periods represented in this study are the 1940-1950s, 1960-1970s, 1980-1990s.

Calculating salinity from resistivity response

A resistivity log is created by sending an electric current into the adjacent formation and then measuring the returned response (Asquith & Krygowski, 2004). The response is converted to a resistivity by using the Archie Method. This technique involves first using the Archie equation: $F = a/\Phi^m$, where F is the formation factor, Φ is the porosity, and (a,m) are Humble constants. Humble constants of a= 0.62 and m= 2.15 were used for unconsolidated sand. The porosity was an assumed value of 0.4 for medium-coarse sand. The resistivity of the water was calculated from the equation $R_w = R_o/F$, where R_o is the resistivity reading from the well log in units of ohm-meters (Whitman, 1965). The reciprocal of R_w equals the groundwater electrical conductivity (C_w), which was converted into units of micro-Siemans per centimeter (µS/cm). This value then allowed for the calculation of salinity as chloride in parts per million (ppm) according to a linear equation: Chlorides = $(0.3^* C_w) - 76.7$. This equation was based on known values of specific conductance and chloride concentration measured in USGS monitoring wells in the study area (Figure 3.1).

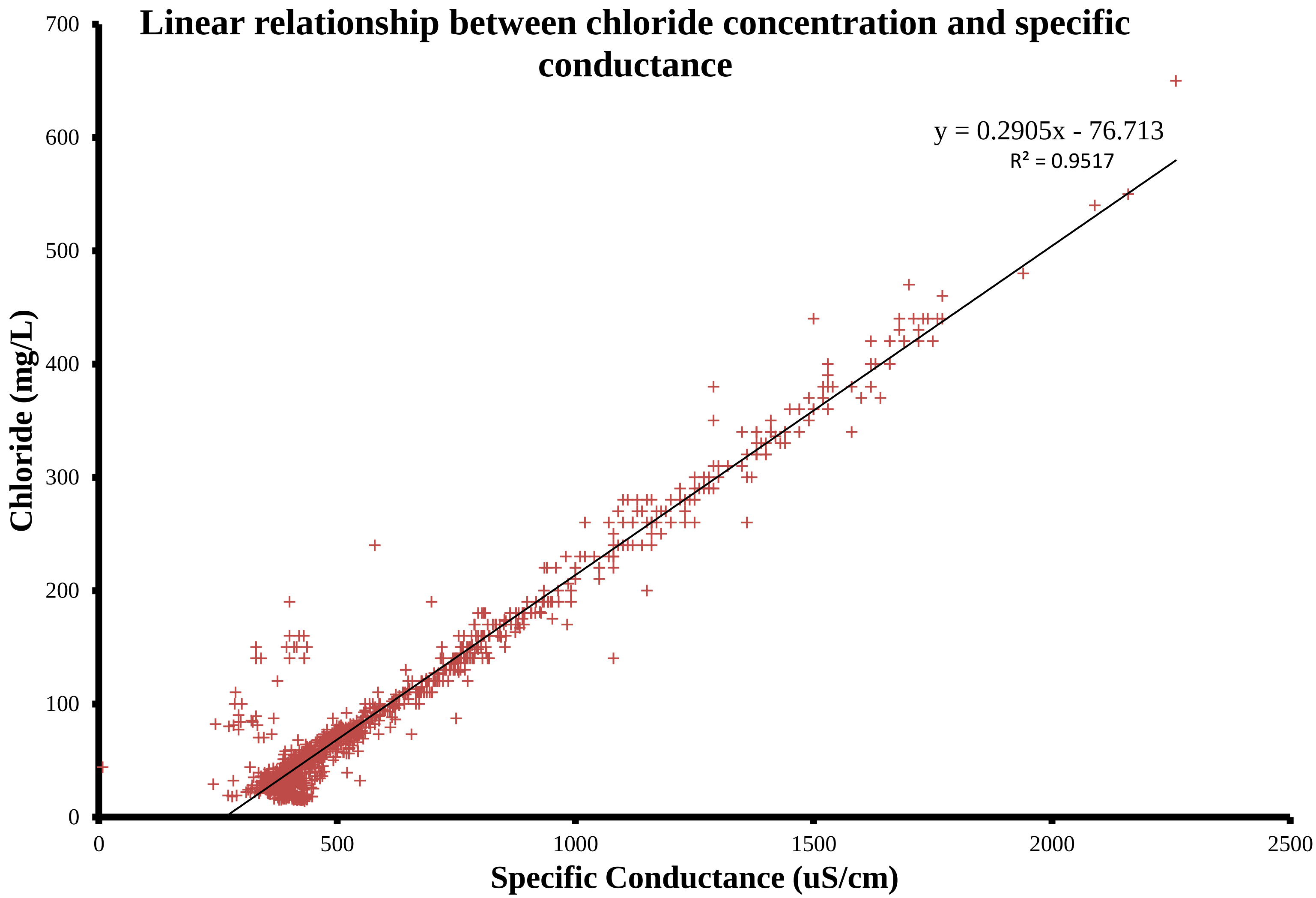

Figure 3.1. Linear relationship between chloride concentration and specific conductance for USGS monitoring wells in the study area. This linear relationship was used to calculate chloride concentration from resistivity values taken from resistivity well logs.

Calculating salinity from SP response

A spontaneous potential log is a record of the voltage that naturally develops between a moving electrode in a well and a fixed electrode at the surface (Asquith & Krygowski, 2004). The SP response is measured in millivolts (mV) and is created by the difference in salinity between the mud filtrate used in the well and the formation water within permeable beds (Asquith & Krygovski, 2004). The salinity difference causes a concentration gradient; thus, for sand beds that are more saline than the drilling fluid, the ions in the sand bed will begin to migrate toward the borehole (Hanor, 1987). Because anions are typically more mobile than cations in aqueous solutions, a charge separation is induced, which is detected by the SP tool. An opposite charge separation is produced in shale beds due to the negative surface charge that is typically present in clay minerals. The negative surface charge retards the movement of anions toward the borehole, thus making the cations more mobile and reversing the SP response (Hanor, 1987).

SP logs were analyzed to determine the shale baseline, as well as the maximum SP deflection in sand beds that were at least fifty feet thick. The difference between the shale baseline and the maximum deflection is called the Static Spontaneous Potential, or SSP (Figure 3.2). Bateman & Konen developed a mathematical method for the determination of formation water resistivity from SSP response (1977). In addition to SSP values, the method requires input of several other well log parameters, including mud weight, mud resistivity (R_m), mud filtrate resistivity (R_{mf}), mud filtrate temperature (T_{mf}), and formation temperature (T_f); values for these parameters were found on the well log header or estimated based on typical values for the area. A currently unpublished spreadsheet developed by Jeffrey Hanor was used to calculate salinity

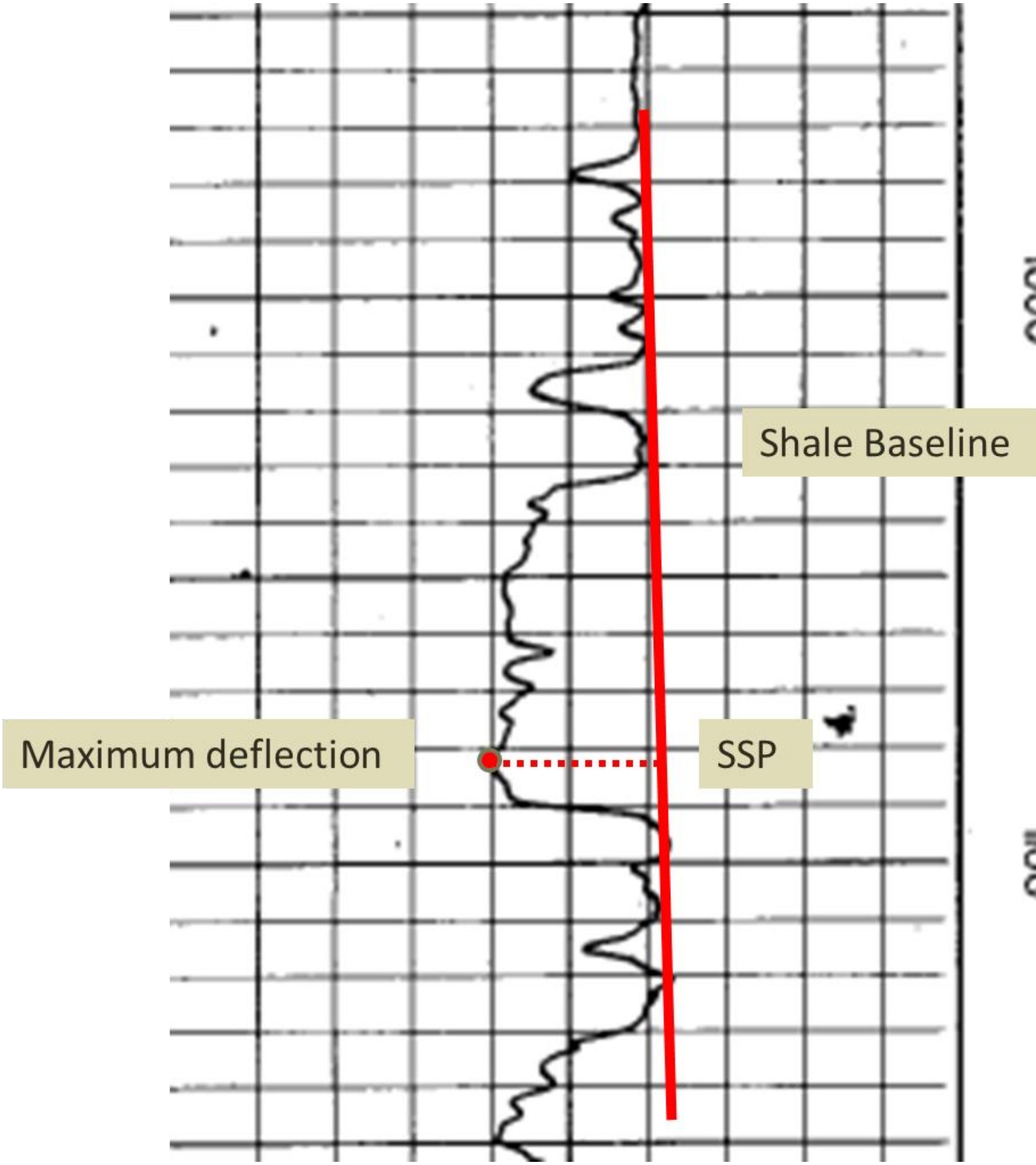

Figure 3.2. Example of a spontaneous potential well log annotated with the shale baseline, maximum deflection, and SSP response. The horizontal scale for this log is 10 mV per each subdivision.

as total dissolved solids (TDS) using the Bateman & Konen method (Hanor, personal communication).

Logs with missing mud information used assumed values, which were based on the values obtained from the well logs at nearby areas. Missing mud filtrate resistivity (R_{mf}) was calculated based on the measured mud resistivity (R_m). This involved first correcting the mud resistivity to a temperature of 75°F using the Hilchie (1984) equation:

$$R_{m(75)} = R_{m(Tm)}\left(\frac{T_m + 6.77}{75 + 6.77}\right)$$

where $R_{m(75)}$ is the mud resistivity at 75°F, $R_{m(Tm)}$ is the mud resistivity at the formation temperature, and T_m is the formation temperature. Then, the resistivity of the mud filtrate at 75°F was calculated by a linear equation: $R_{mf(75)} = a*R_{m(75)} + b$ (Funayama & Hanor, 1997), where a=0.8166 and b= -0.066. The constants in this equation were derived from a linear comparison of known mud resistivity and mud filtrate resistivity values from wells used in the study (Figure 3.2). It is important to note that the shallow (< 900 feet depth) resistivity values for this study were reported in total chloride, while the deeper (> 900 feet depth) salinity was calculated in TDS.

Comparison to USGS Water Well data

Chloride concentrations for 197 USGS monitoring wells in the Lake Charles industrial area were obtained (Lovelace, personal communication) and used to support the well log salinity results. These water quality data came from wells screened in all three aquifer layers. The oldest water sample was from 1940, and the samples spanned to 2013. As such, this data also helped to show trends in the groundwater salinity over time.

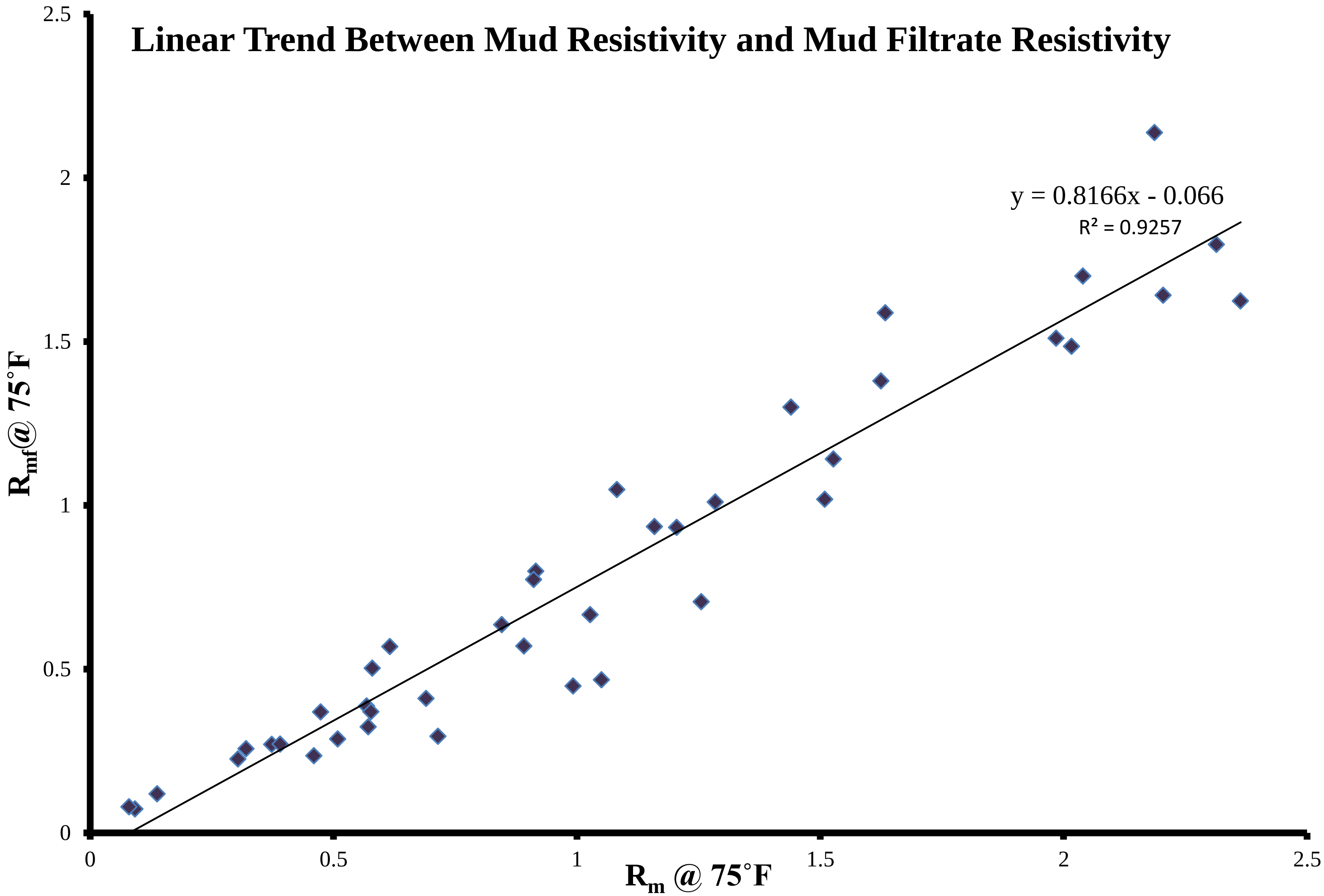

Figure 3.3. Linear relationship between mud resistivity and mud fluid resistivity at 75˚F. All data points in this figure are taken from oil and gas wells drilled in the study area from 1960-1990 (Mud fluid resistivity was not recorded on well logs until the end of the 1950s).

RESULTS

Shallow Chloride Data

Chloride concentration values were acquired for the 200’, 500’, and 700’ sands in the Lake Charles industrial area. Tables 1-3 in the Appendix contain the well details and chloride data from the resistivity analysis. Figures 4.1-4.9 display the shallow (<900 ft) salinity information.

Chloride values for the 200’ sand range from <50 milligrams per liter (mg/L) to a high of 480 mg/L (Figures 4.1 - 4.3). The majority of the high salinity values occur in the center of the industrial district, with a few localized spikes occurring in the northern and southern areas. In the 500’ sand, chloride concentrations range from <50 to 417 mg/L (Figures 4.4 - 4.6). The highest salinity occurs in the central area of the industrial area for all time periods. Smaller, less saline bodies are also visible to the north and south. The 700’ sand has chloride values ranging from <50 to 530 mg/L (Figures 4.7 – 4.9). In this sand layer, the entire industrial area contains relatively high salinity values, with spikes of even greater values in the central, northern, and southern areas. The central chloride body has the highest chloride concentrations and typically the largest areal extent.

Deep TDS Data

TDS concentrations were obtained for deep (>900 feet) groundwater beneath the Lake Charles industrial district. A total of 15 SP well logs were analyzed in the area near the Lockport salt dome. All of the logs utilized for this portion of the study were recorded during the 1950s, as this decade has the best well coverage. TDS concentrations were averaged over 1,000 foot intervals then contoured. Figures 4.10-4.11 display these salinity contours. Table 4 of the

Appendix contains the well details and TDS concentrations attained from the SP analysis. Overall, TDS values range from 16 to 207 grams per liter (g/L). The depth interval with the highest salinity readings is from 5000-6000 feet. The highest TDS values (for all depth intervals) tend to occur along the northern and southern flanks of the underlying salt dome.

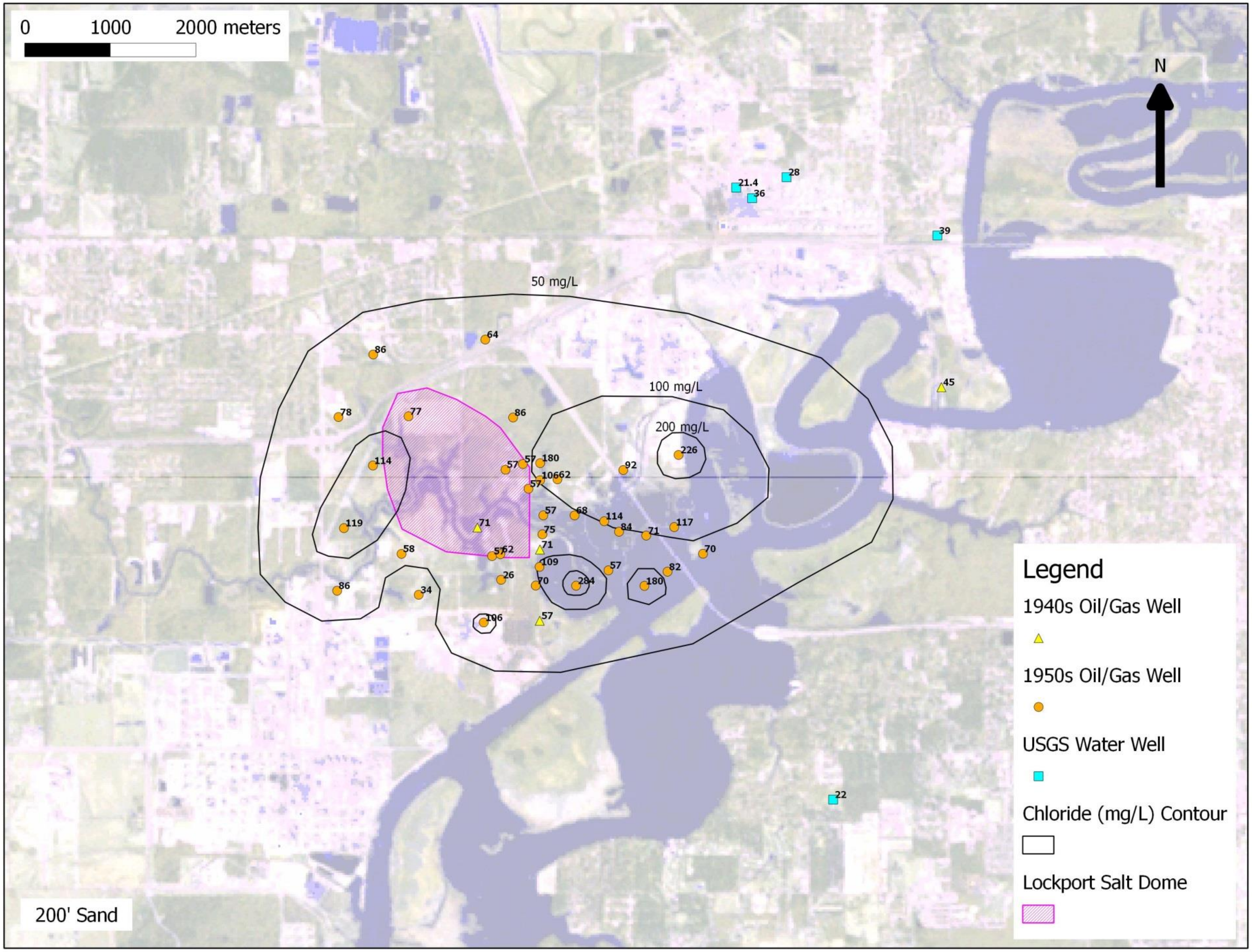

Figure 4.1. Chloride isoconcentration contours for the 200' sand for 1940-50s data. Figure made in QGIS (2013).

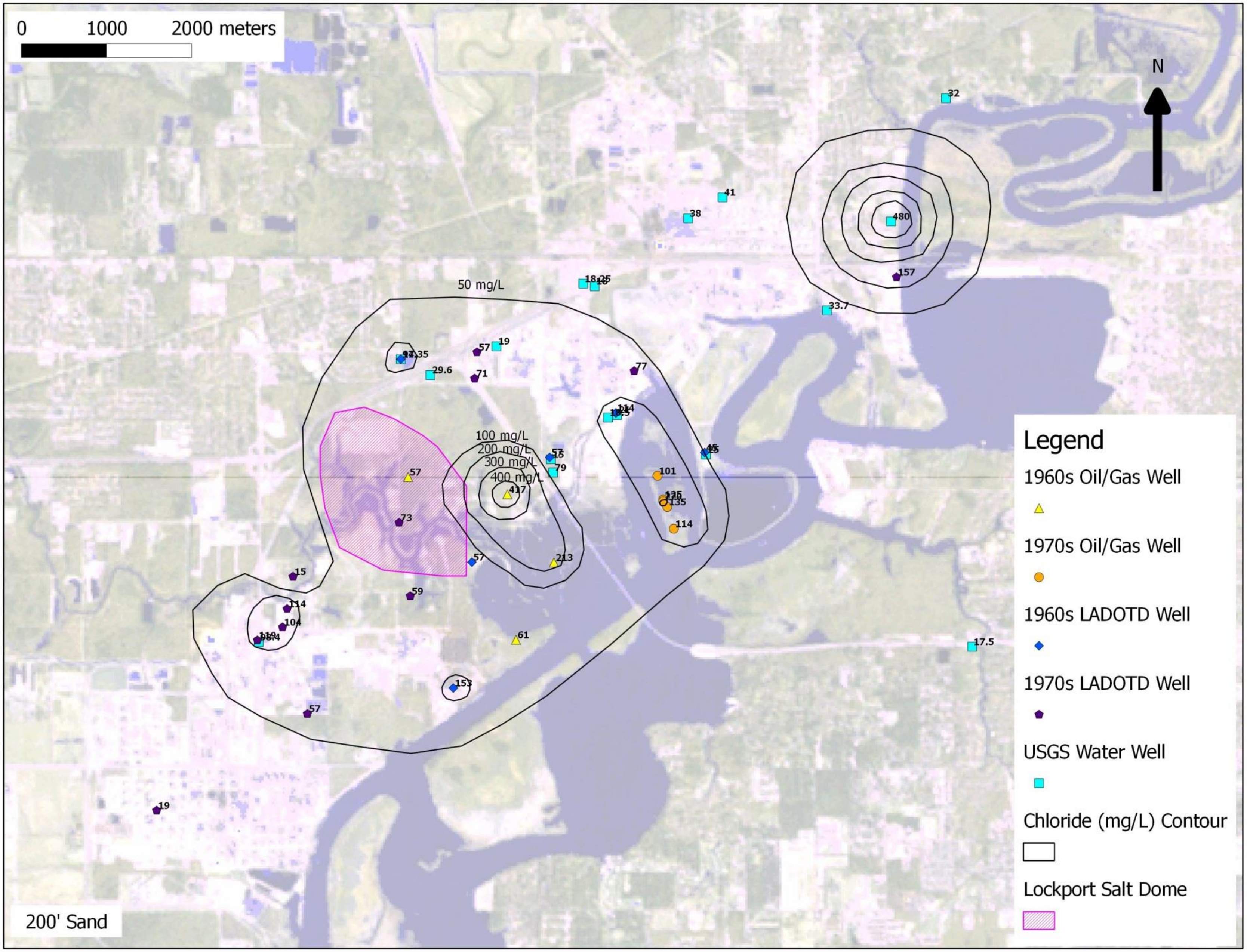

Figure 4.2. Chloride isoconcentration contours for the 200' sand for 1960-70s data. Figure made in QGIS (2013).

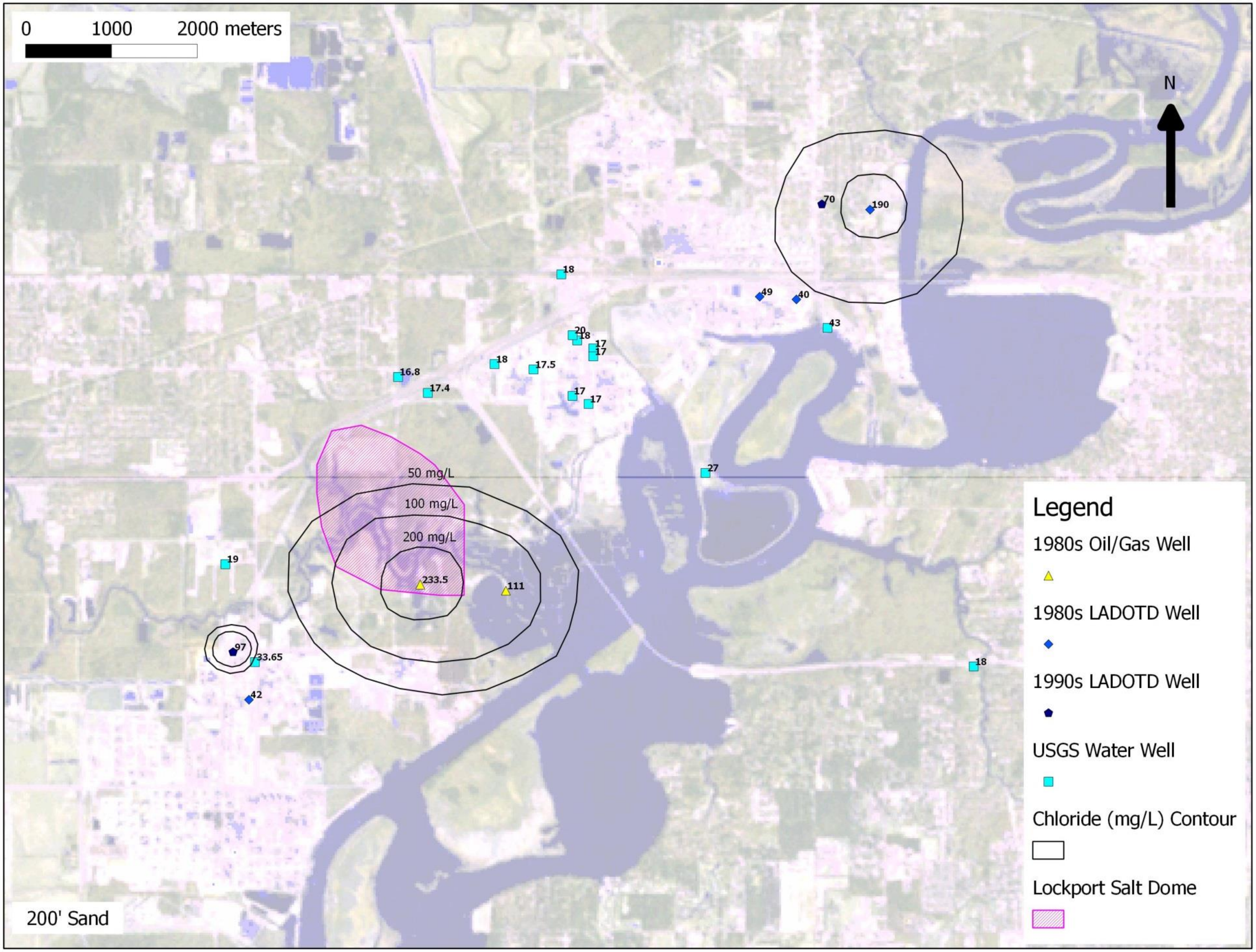

Figure 4.3. Chloride isoconcentration contours for the 200' sand for 1980-90s data. Figure made in QGIS (2013).

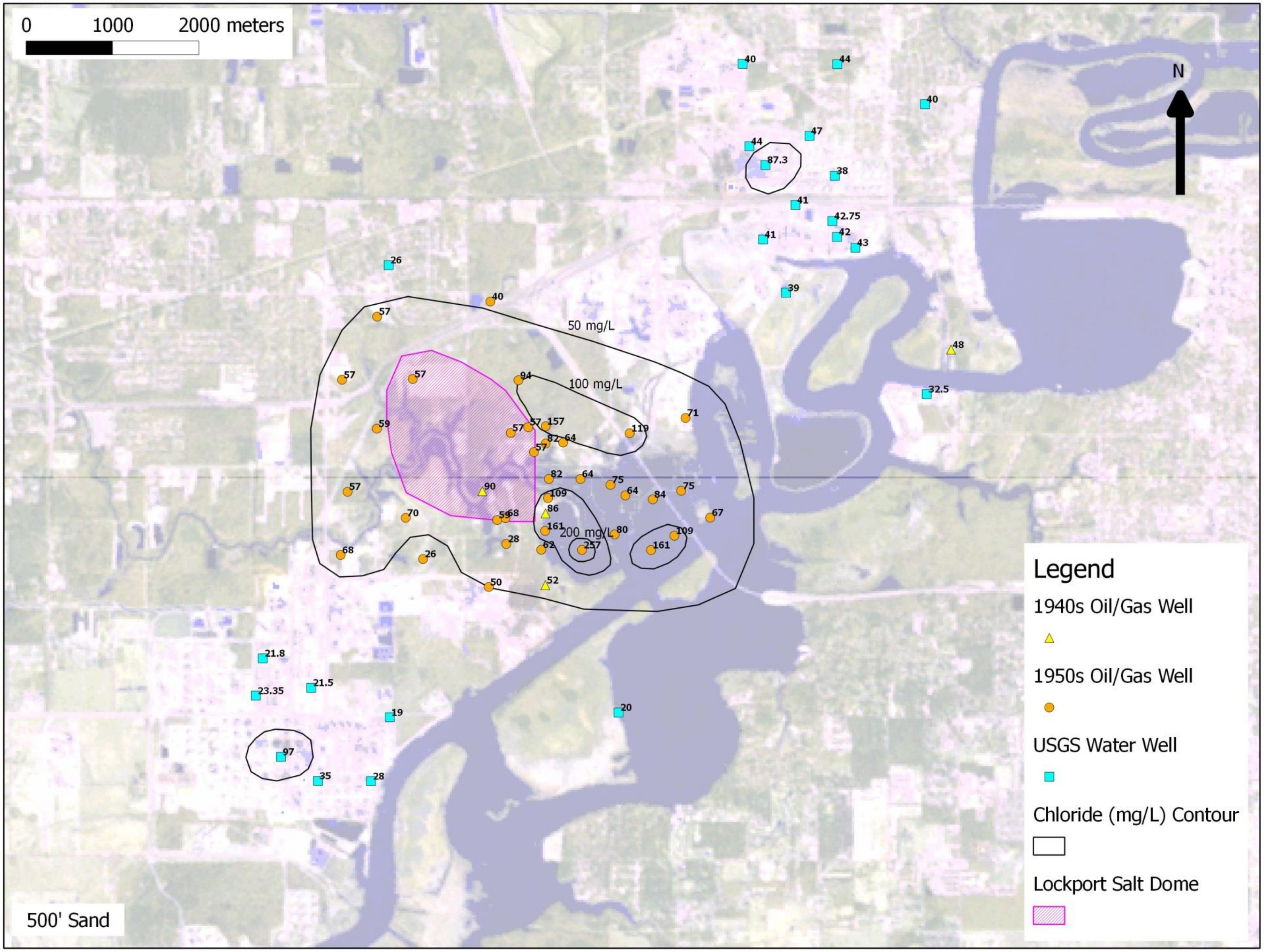

Figure 4.4. Chloride isoconcentration contours for the 500' sand for 1940-50s data. Figure made in QGIS (2013).

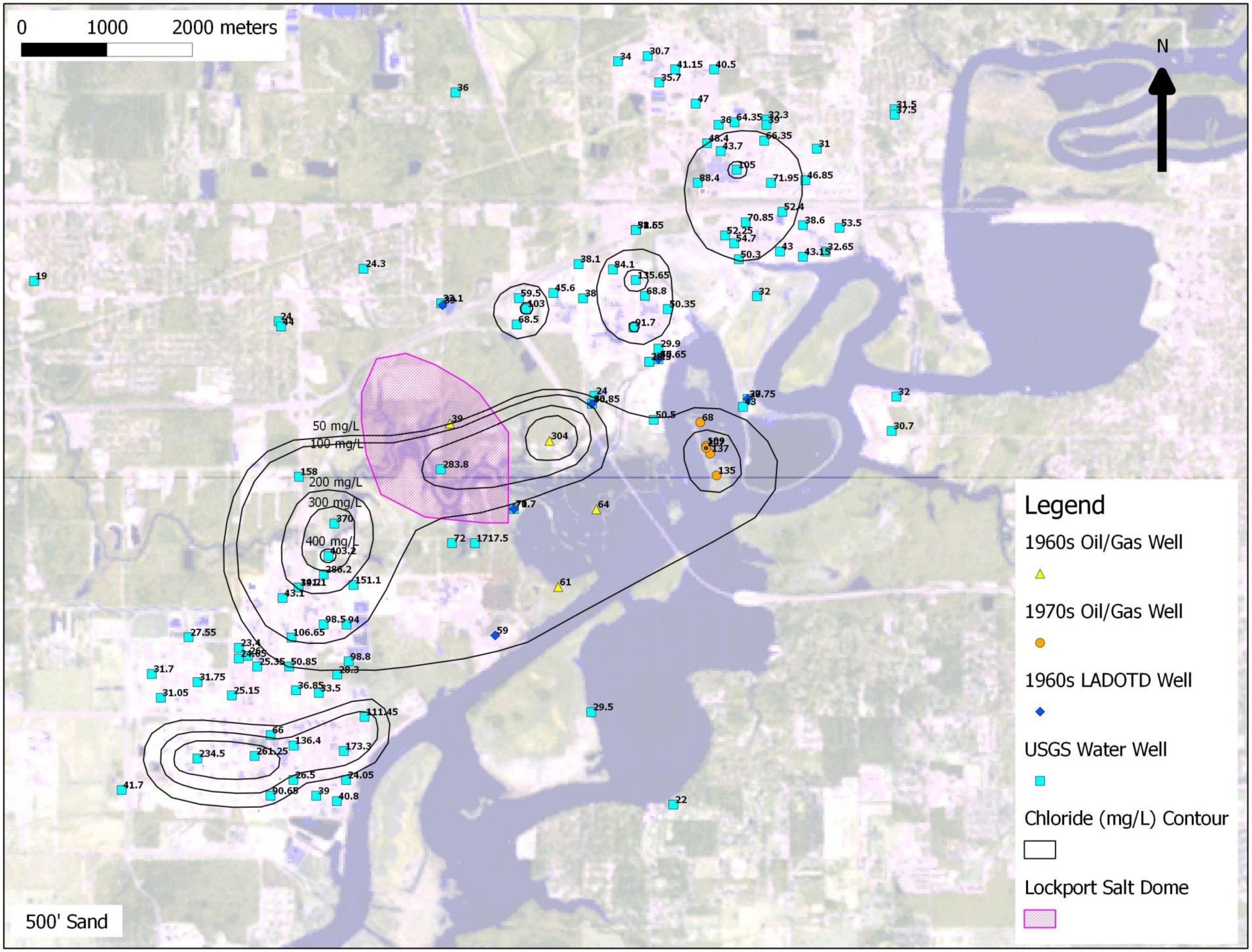

Figure 4.5. Chloride isoconcentration contours for the 500' sand for 1960-70s data. Figure made in QGIS (2013).

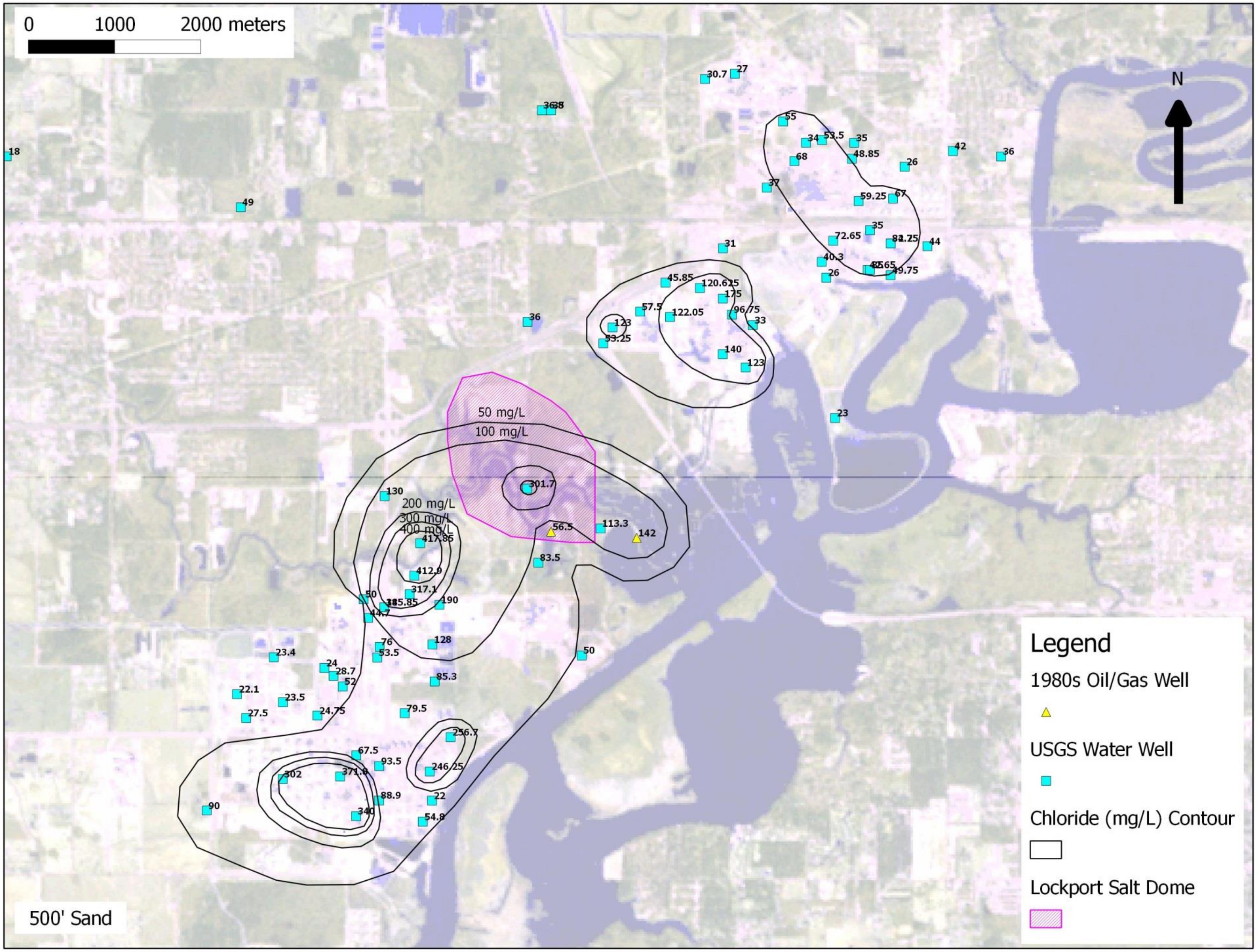

Figure 4.6. Chloride isoconcentration contours for the 500' sand for 1980-90s data. Figure made in QGIS (2013).

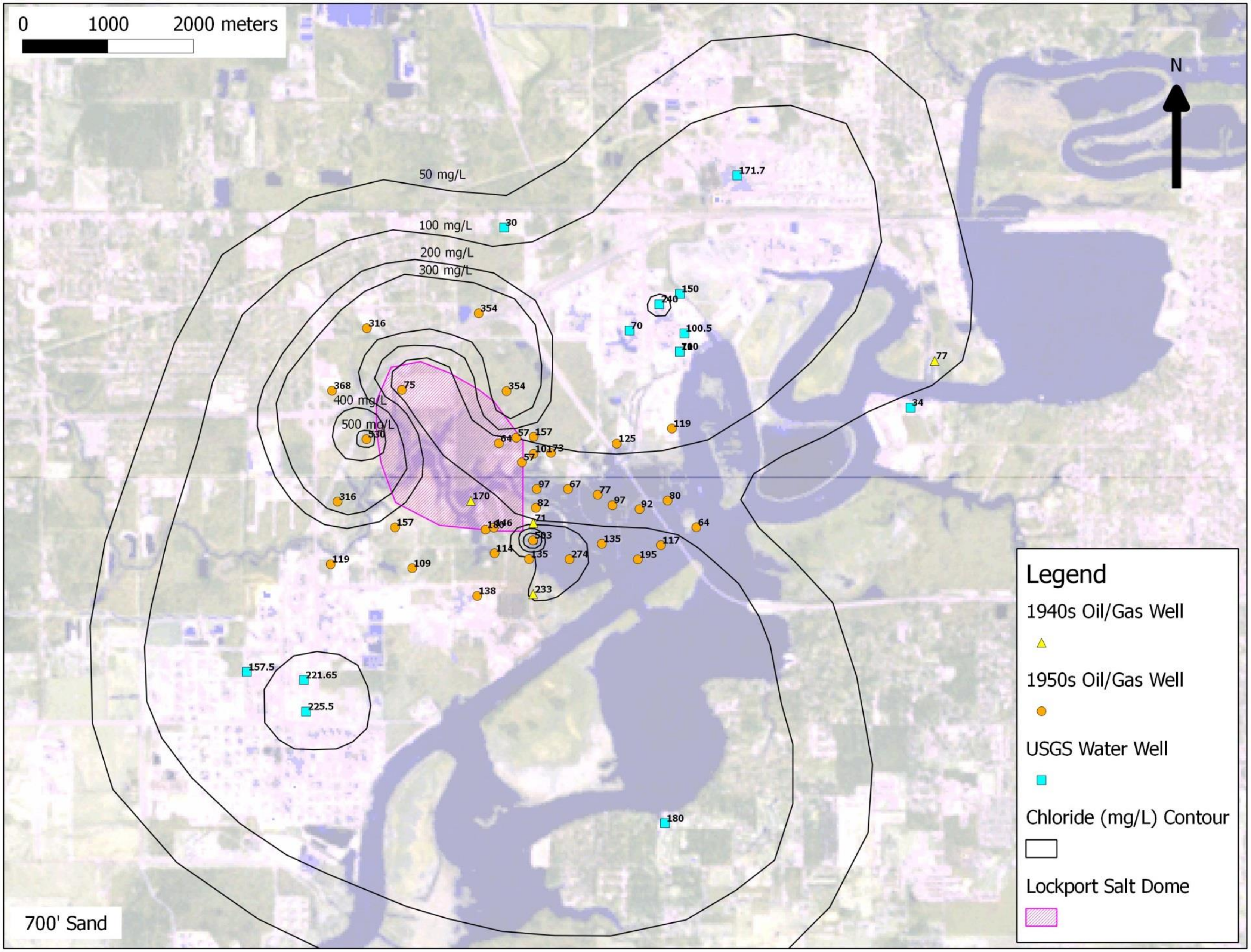

Figure 4.7. Chloride isoconcentration contours for the 700’ sand for 1940-50s data. Figure made in QGIS (2013).

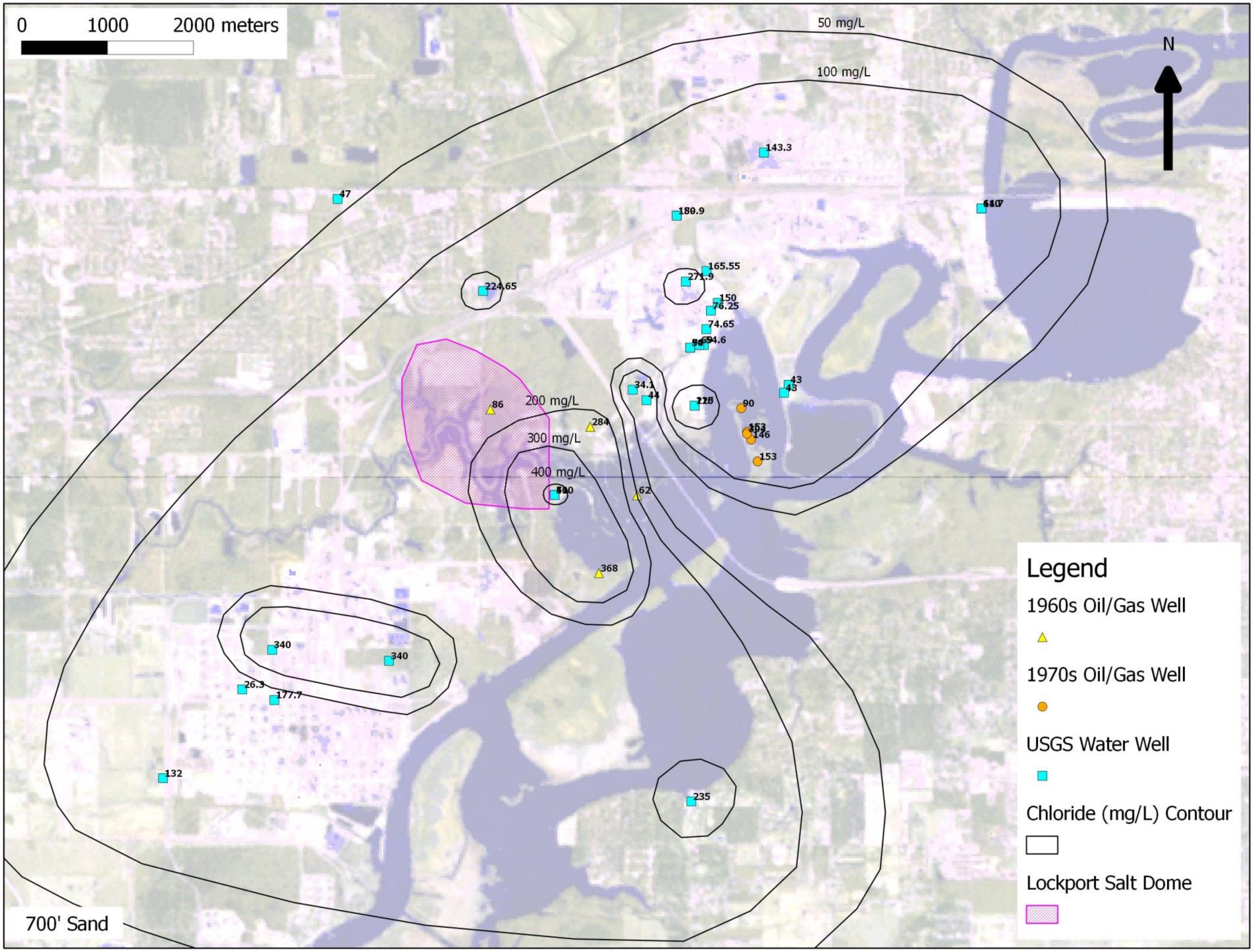

Figure 4.8. Chloride isoconcentration contours for the 700’ sand for 1960-70s data. Figure made in QGIS (2013).

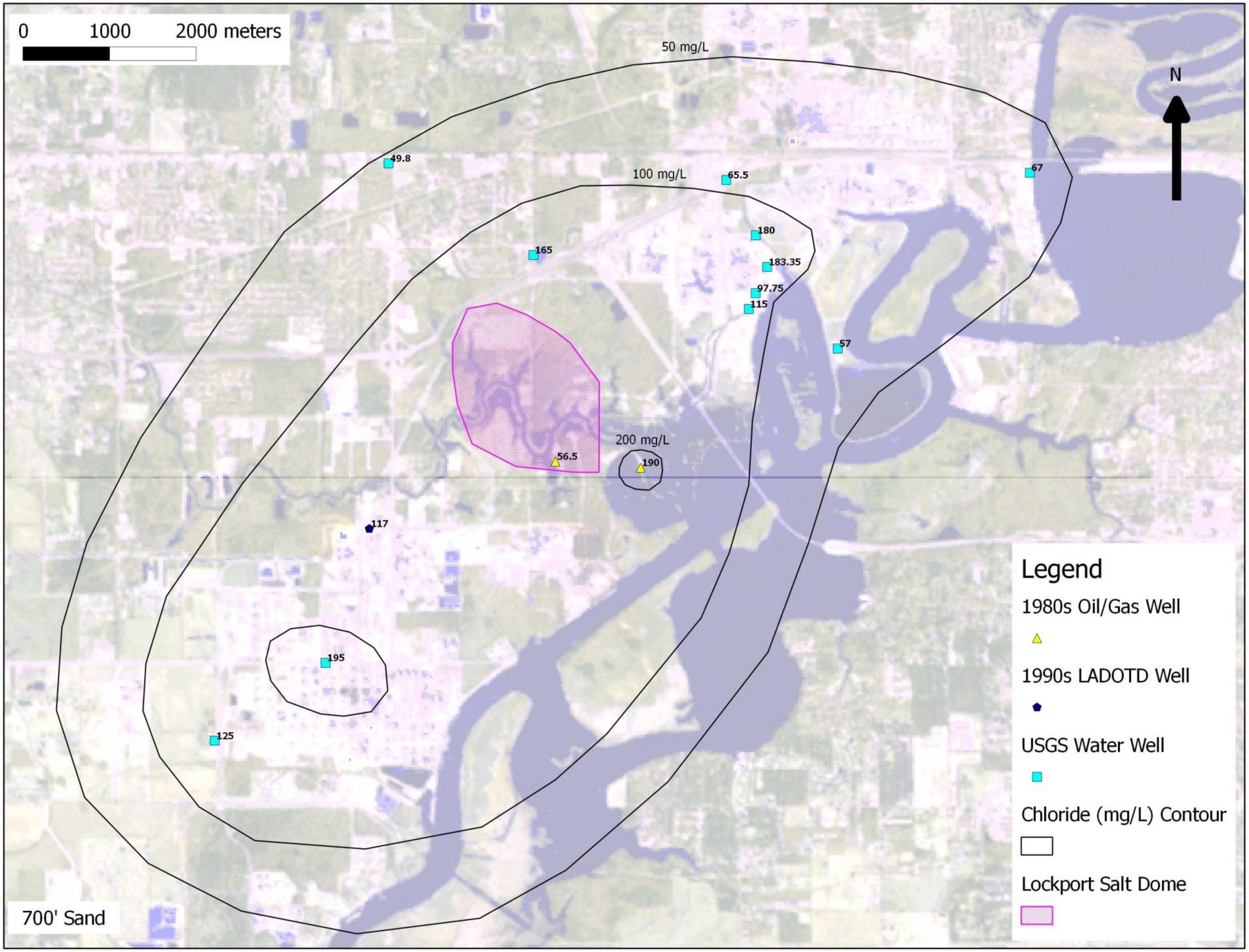

Figure 4.9. Chloride isoconcentration contours for the 700' sand for 1980-90s data. Figure made in QGIS (2013).

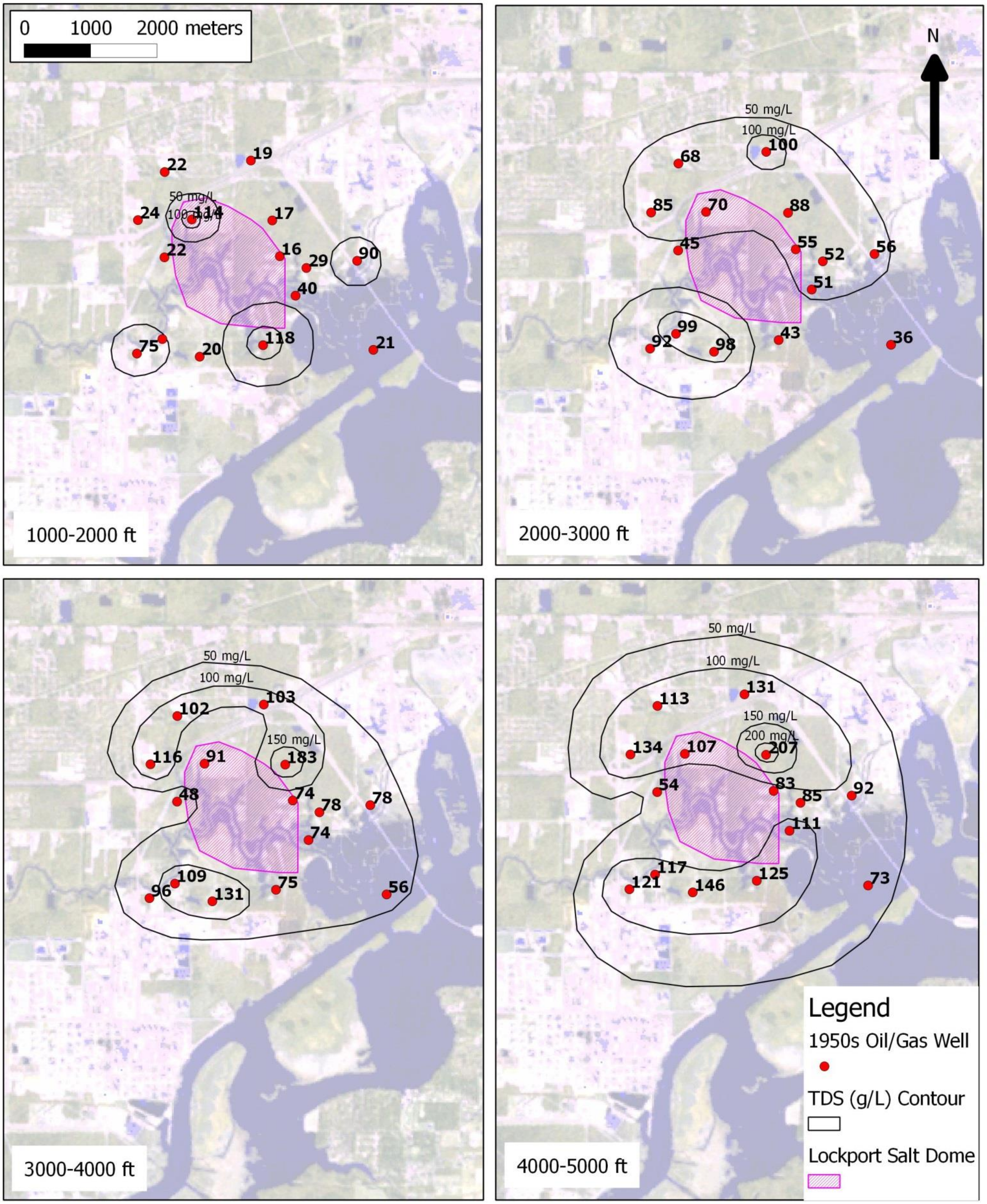

Figure 4.10. TDS isoconcentration contours for 1000-5000 feet depth for 1950s data. Contour interval equals 50 g/L. Figure was made in QGIS (2013).

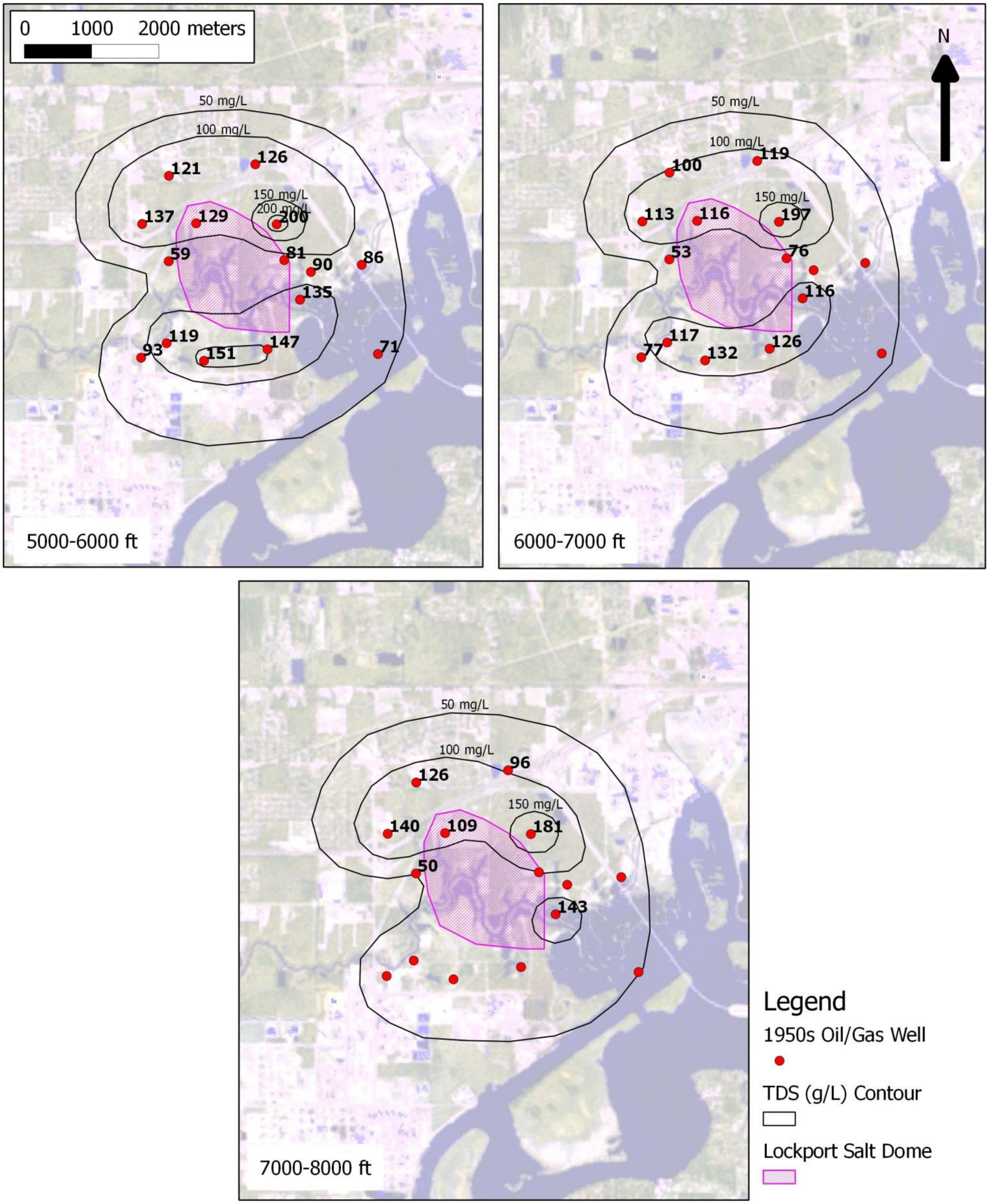

Figure 4.11. TDS isoconcentration contours for 5000-8000 feet depth for 1950s data. Contour interval equals 50 g/L. Figure was made in QGIS (2013).

DISCUSSION

Shallow-Depth Chloride Data

200’ Sand

The 200’ sand has actually become less saline over time. In the 1940-50s, the 200’ sand has elevated salinity values near the center of the industrial area (Figure 4.1). A surficial source of salinity for this central area is likely due to the fact that the chloride concentrations actually get lower in the underlying 500’ sand. Vertical leakage of saline groundwater is plausible because throughout the whole industrial area, clay units have been weathered and fractured; this weathering has augmented the vertical conductivity and allowed for increased vertical movement of groundwater through confining clays (Milner, personal communication). The high salinity values are clustered around the Lockport dome oil field, so the source of salinity is probably due to oilfield operations at the time.

In the 1960-70s, the 200’ sand continues to have localized areas of high chloride concentrations (Figure 4.2). Again, the source appears to be surficial, as 500’ sand chloride values are lower. The highest chloride concentrations are >400 mg/L and again appear to be emanating from the areas with active oil wells.

Chloride concentrations decrease considerably through the 1980-90s, though a few localized spikes still exist (Figure 4.3). Just as in previous decades, the chloride contamination in the central area appears to be coming from a surficial source, either oil and gas operations or industrial operations. Two smaller salinity spikes during this time period occur near pumping wells and appear to be upconing from depth.

500’ Sand

The 500’ sand is the most heavily pumped aquifer layer in the Lake Charles area. As such, many of the high chloride values in this aquifer layer appear to be due to high pumping rates that draw in saline water from surrounding strata. In the 1940-50s, the majority of the high chloride values are located in the central industrial area (Figure 4.4). A large area of >50 mg/L chloride covers the entire central area, with three smaller zones of >100 mg/L chloride. The >100 mg/L zones appear to be caused by both surficial and deep sources. Chloride values in the 200’ sand directly above them are higher, and saline water has likely leaked down from the overlying aquifer. However, chloride values in the 700’ sand directly below are also higher, so saline water also may have come up from depth. In many locations, the 500’ sand and 700’ sand are separated by very thin confining clay units (Lovelace, 1999), so movement of saline groundwater between these aquifer layers is plausible. Two smaller, localized spikes in chloride also occur to the north and south of the large chloride body. These small spikes are located near pumping wells, and thus, are likely due to upwelling of saline groundwater from depth. Further confirmation of upwelling comes from the fact that chloride values in the 700’ sand directly below these saline spikes are higher than the chloride values in the 500’ sand.

In the 1960-70s, the high chloride areas expand considerably (Figure 4.5). The largest area of salinity is still located in the central area of the industrial district. A few of the spikes in salinity within the central chloride body appear to be due to surficial contamination from oil/gas activity. Some of the higher values of chloride, though, are not located near oilfield activity, and curiously, they are also far from pumping centers. Thus, the high salinity in these spikes must have a different source. Again, the smaller chloride bodies to the north and south are located in areas of heavy pumping and appear to be upwelling from depth, as salinity values in the underlying 700’ sand in these areas is higher than in the 500’ sand.

The 1980-90s contours show similar patterns to the previous decades (Figure 4.6). The central chloride body is the largest. Salinity does not appear to be coming from directly above or directly below the high salinity areas. Also, the central area has very few pumping wells, which means the high salinity has to have a different source and mechanism of travel. The high chloride bodies to the north and south are again likely due to upwelling of saline groundwater from depth.

700’ Sand

The 700’ sand was the first aquifer layer in Lake Charles to start having high salinity values; as such, many of the pumping wells in this aquifer layer were abandoned several decades ago, which has allowed for some aquifer recovery from saltwater upconing. The source of salinity for the 700’ sand appears to be from depth, as chloride values in the 700’ sand are nearly always higher than those of the overlying 500’ sand. The 1940-50s contours for the 700’ sand show that nearly the entire industrial area contains elevated salinity values (Figure 4.7). The highest values are located in the central area, and tend to surround the Lockport salt dome present at depth. Again, this central area has no pumping wells, so another mechanism must be responsible for bringing saline water to shallow depths. Small spikes in salinity are also present in the northern and southern areas of the industrial district; these spikes are located in pumping areas and appear to be caused by upwelling of higher salinity groundwater from depth.

There is less well control for the 1960-70s, but the general pattern holds (Figure 4.8). The central chloride body contains the highest salinity, and is not located near pumping wells.

Spikes in salinity to the north and south are located near pumping wells that cause upwelling of saline water from depth.

Even fewer wells are available for the 1980-90s, but the wells that are present are consistent with the previous decades, though all salinity values are a bit lower (Figure 4.9). The general freshening of the groundwater may be due to the cessation of high rates of pumping from this sand layer after high chloride groundwater was first noticed. The aquifer layer appears to have recovered from the high pumping rates in a very short period of time. Only two data points are located in the central area. One of these points does show a spike in salinity consistent with previous decades. The high chloride bodies are still present to the north and south in the high pumping areas, as well.

Deep TDS Data

The deep TDS data reveals that the source of salinity for some parts of the central chloride body are likely coming from the Lockport salt dome (Figures 4.10 – 4.11). Contours show a general trend of high salinity on the northern and southern flanks of the salt dome. It appears that there are two separate faults that are allowing salt dome brine to travel up to shallower depths. Previous stratigraphy work has suggested the presence of faults above the Lockport salt dome in Lake Charles (Hodges et. al., 1963) so this theory is plausible.

The brine is likely moving upward to escape from the overpressured zone below. An overpressure mechanism for fluid flow has been purported by Hanor for brine movement near the Welsh salt dome in nearby Jefferson Davis parish (Hanor, 1987). A similar hypothesis for high salinity waters in South Louisiana was proposed by Stoessell and Prochaska (2005), who performed chemical analyses on groundwater samples; they determined that the chemical composition of the groundwater was consistent with dissolution of salt diapirs, with brines travelling up fault conduits.

CONCLUSIONS

The central chloride body in the Lake Charles industrial district has had several sources of salinity throughout recent decades. Both surficial contamination and deep salt dome dissolution appear to be contributing to most of the high salinity in the area. Formation water may also be contributing to the salinity of upconing groundwater. A marine source of saline water is unlikely due to the fact that there is no evidence of a salinity gradient coming from the south.

Dissolution of the Lockport salt dome appears to be the cause of the previously unexplained salinity spikes in the central area of the industrial district. These high chloride zones are located in areas with low 200’ salinity; thus, the salinity must be coming from below. However, the high chloride zones are not close to pumping areas, so the upwelling of saline water from depth had no known mechanism. This research has revealed that the anomolous salinity spikes line up with the brine plumes coming from the Lockport salt dome at deeper depths. Thus, upwelling of brine from the salt dome provides an explanation for the appearance of saline water, as the brine can be transported upward due to overpressure forces and conduit faults. It appears that saline groundwater is transported via faults to the 700’ sand layer and spreads throughout the aquifer. Then, the 700’ sand acts as a saline source to the shallower aquifer layers where they are heavily pumped.

REFERENCES

Anderson, C., 2011, Sources of salinization in the Baton Rouge aquifer system: Southeastern Louisiana: Louisiana State University Graduate Thesis.

Asquith, G., and D. Krygowski, 2004, Basic well log analysis, second edition: American Association of Petroleum Geologists Methods in Exploration Series, No. 16.

Barlow, P.M., and E.G. Reichard, 2010, Saltwater intrusion in coastal regions of North America: Hydrogeology Journal, v. 18, p. 247–260.

Bateman, R.M, and C.E. Konen, 1977, The log analyst and the programmable pocket calculator: Society of Petrophysicists & Well Log Analysts, v. 43.5.

Beckman, J.D., and A.K. Williamson, 1990, Salt-dome locations in the Gulf Coastal Plain, South-Central United States: United States Geological Survey Water-Resources Investigations Report, 90-4060.

Bennett, S.S., and J.S. Hanor, 1987, Dynamics of subsurface salt dissolution at the Welsh Dome, Louisiana Gulf Coast: Dynamic Geology of Salt and Related Structures, p. 653-77.

Bieber, P.P., and M.J. Forbes, Jr., 1966, Pumpage of water in Lousiana, 1965: Louisiana Department of Public Works and Department of Conservation Louisiana Geological Survey Water Resources Pamphlet No. 20.

Bird, D.E., K. Burke, S.A. Hall, and J.F. Casey, 2005, Gulf of Mexico tectonic history: hotspot tracks, crustal boundaries, and early salt distribution: American Association of Petroleum Geologists Bulletin 89.3, p. 311-28.

Cardwell, G.T., and W.H. Walter, 1979, Pumpage of water in Louisiana, 1975: Louisiana Department of Transportation and Development Water Resources Special Report No. 2.

Dial, D.C., 1970, Pumpage of water in Louisiana, 1970: Louisiana Department of Public Works and Department of Conservation Louisiana Geological Survey Water Resources Pamphlet No. 26.

Funayama, M., and J.S. Hanor, 1995, Pore water salinity as a tool for evaluating reservoir continuity and fluid migration pathways in the Wilcox Group of Central Louisiana: Gulf Coast Association of Geological Societies Transactions, v.45 p. 195-201.

Funayama, M., and J.S. Hanor, 1997, Spreadsheet program for calculating in situ properties of formation waters from SP-resistivity logs.

Halbouty, M.T, 1979, Salt Domes: Gulf Region, United States & Mexico, 2nd Edition: Gulf Publishing Company.

Hanor, J.S., 1987, Origin and migration of subsurface sedimentary brines: Lecture notes for Society for Sedimentary Geology Short Course No. 21.

Harder, A.H., 1960, The geology and ground-water resources of Calcasieu Parish Louisiana: Geological Survey Water-Supply Paper 1488.

Hodges, A.L. Jr., S.M. Rogers, and A.H. Harder, Gas and brackish water in fresh-water aquifers, Lake Charles area, Louisiana: State of Louisiana Department of Conservation Geological Survey and Department of Public Works Water Resources Pamphlet No. 13.

Ingebritsen, S.E., W.E. Sandford, and C.E. Neuzil, 2006, Groundwater in geologic processes, 2nd edition, Cambridge, Cambridge University Press, 536 p.

Lovelace, J.K., 1991, Water use in Louisiana, 1990: Louisiana Department of Transportation and Development Water Resources Special Report No. 6.

Lovelace, J.K., 1998, Distribution of saltwater in the Chicot aquifer system in the Calcasieu parish area, Louisiana, 1995-1996: Department of Transportation and Development Water Resources Technical Report No. 62.

Lovelace, J.K., 1999, Distribution of saltwater in the Chicot aquifer system of southwestern Louisiana, 1995-1996: Department of Transportation and Development Water Resources Technical Report No. 66.

Lovelace, J.K., and P.M. Johnson, 1996, Water use in Louisiana, 1995: Louisiana Department of Transportation and Development Water Resources Special Report No. 11.

Lurry, D.L., 1987, Pumpage of water in Louisiana, 1985: Louisiana Department of Transportation and Development Water Resources Special Report No. 4.

Milner, L.R., and T.P. Van Biersel., 2006, Updated geology and saltwater intrusion for the Chicot aquifer of southwest Louisiana: Coastal Environment and Water Quality, p. 153-166.

Nyman, D.J., 1984, The occurrence of high concentrations of chloride in the Chicot aquifer system of southeastern Louisiana: Department of Transportation and Development Water Resources Technical Report No. 33.

Nyman, D.J., K.J. Halford, and A. Martin, Jr., 1990, Geohydrology and simulation of flow in the Chicot aquifer system of southwestern Louisiana: Department of Transportation and Development Water Resources Technical Report No. 50.

Sargent, P., 2002, Water use in Louisiana, 2000: Louisiana Department of Transportation and Development Water Resources Special Report No. 15.

Sargent, P., 2007, Water use in Louisiana, 2005: Louisiana Department of Transportation and Development Water Resources Special Report No. 16.

Sargent, P., 2011, Water use in Louisiana, 2010: Louisiana Department of Transportation and Development Water Resources Special Report No. 17.

Snider, J.L., and M.J. Forbes, Jr., 1961, Pumpage of water in Louisiana, 1960: Louisiana Department of Public Works and Department of Conservation Louisiana Geological Survey.

Stoessell, R.K., and L. Prochaska, 2005, Gulf Coast Association of Geological Societies Transactions, v. 55, p. 794-808.

Tomaszewski, D.J., 1996, Distribution and movement of saltwater in aquifers in the Baton Rouge area, Louisiana, 1990-92: Department of Transportation and Development Water Resources Technical Report No. 59.

United States Environmental Protection Agency, 2012, <http://water.epa.gov /infrastructure/drinkingwater/sourcewater/protection/solesourceaquifer.cfm> Accesed November 14, 2012.

United States Geological Survey Louisiana Water Science Center, 2013, <http:// la.water.usgs.gov/WellsByParishMap.asp?Parish=Calcasieu> Accessed March 2, 2013.

Wallace, W.E. Jr., 1944, Structure of South Louisiana deep-seated domes, Bulletin of the American Association of Petroleum Geologists, v. 28 no. 9.

Walter, W.H., 1982, Pumpage of water in Louisiana, 1980: Louisiana Department of Transportation and Developemnt Water Resources Special Report No. 3.

Welch, S.E., and J.S. Hanor, 2011, Sources of elevated salinity in the Mississippi River Alluvial Aquifer, south-central Louisiana, USA: Applied Geochemistry, v.26, p. 1446-1451.

Whitman, H.M., 1965, Estimating water quality from electrical logs: Louisiana Geological Survey Water Resources Pamphlet No. 16.

APPENDIX: TABLES OF WELL DETAILS AND SALINITY VALUES

Table 1. Well Details and Chloride Data from Oil and Gas Wells.

Well Serial Number	Well Name	Well #	Permit Date	Surface Latitude (Nad83)	Surface Longitude (Nad83)	Well Status	Measured Depth (feet)	Beginning of Logged Interval (depth in feet)	200' sand Resist. (ohm-meters)	200' Cl^- (mg/L)	500' sand Resist. (ohm-meters)	500' Cl^- (mg/L)	700' sand Resist. (ohm-meters)	700' Cl^- (mg/L)
54382	I R BORDAGES	16	11/8/1954	30.2139	-93.2992	Shut-in Productive Wells--Future Utility (Oil)	7505	165	52	180	57	157	57	157
55838	VUA; ALICE CARMOUCHE ET AL	5	3/9/1955	30.2041	-93.305	P&A Oil Producer	6800	80	100	57	98	59	52	180
56528	FARQUHAR SWD	16	5/9/1955	30.20431	-93.304	Salt Water Disposal Wells--Conventional	5059	184	96	62	92	68	60	146
59904	LORRAINE E W WILLIAMS GAS UNIT 2	1	1/10/1956	30.2188	-93.3152	P&A Gas & Condensate Producer	9830	119	87	77	100	57	88	75
59903	SAM H JONES ET AL	1	1/10/1956	30.2187	-93.3237	P&A Gas & Condensate Producer	10277	121	86	78	100	57	30	368
60037	ROSALIE SMITH ET AL UNIT	1	1/22/1956	30.207	-93.323	P&A Dry Hole	9800	220	68	119	100	57	34	316
60137	MAPLEWOOD HOUSING CORP	1	1/29/1956	30.2253	-93.3195	P&A Gas & Condensate Producer	9933	122	82	86	100	57	34	316

Table 1. Well Details and Chloride Data from Oil and Gas Wells.

Well Serial Number	Well Name	Well #	Permit Date	Surface Latitude (Nad83)	Surface Longitude (Nad83)	Well Status	Measured Depth (feet)	Beginning of Logged Interval (depth in feet)	200' sand Resist. (ohm-meters)	200' Cl^- (mg/L)	500' sand Resist. (ohm-meters)	500' Cl^- (mg/L)	700' sand Resist. (ohm-meters)	700' Cl^- (mg/L)
60195	FARQUHAR	19	1/30/1956	30.2016	-93.3039	Shut-in Productive Wells--Future Utility (Oil)	6807	169	130	26	127	28	70	114
60504	I R BORDAGES	18	2/27/1956	30.21871	-93.3025	P&A Oil Producer	10003	197	82	86	78	94	31	354
61496	KEARNEY HEIRS ET AL GAS UNIT 9	1	5/17/1956	30.21361	-93.3195	P&A Dry Hole	9806	110	70	114	98	59	22	530
61495	CITIES SERV REFG CORP GAS U 7	1	5/17/1956	30.22691	-93.3059	P&A Dry Hole	9883	183	95	64	114	40	31	354
62995	I R BORDAGES SWD	19	9/15/1956	30.2138	-93.3013	P&A Producer	6750	100	100	57	100	57	100	57
63919	I R BORDAGES SWD	20	11/12/1956	30.21321	-93.3034	Salt Water Disposal Wells--Conventional	7869	85	100	57	100	57	95	64
65129	OLIN MATHIESON CHEM CORP	1	2/21/1957	30.21381	-93.275	Orphan Wells (Gas & Condensate)	11460	285	---	---	68	119	51	185

Table 1. Well Details and Chloride Data from Oil and Gas Wells.

Well Serial Number	Well Name	Well #	Permit Date	Surface Latitude (Nad83)	Surface Longitude (Nad83)	Well Status	Measured Depth (feet)	Beginning of Logged Interval (depth in feet)	200' sand Resist. (ohm-meters)	200' Cl^- (mg/L)	500' sand Resist. (ohm-meters)	500' Cl^- (mg/L)	700' sand Resist. (ohm-meters)	700' Cl^- (mg/L)
65795	I R BORDAG ES SWD	22	4/18/1957	30.2112	-93.3006	Salt Water Disposal Wells--Convent ional	7492	85	100	57	100	57	100	57
66720	LOCKE-MOORE	1	6/25/1957	30.2148	-93.2824	P&A Dry Hole	9400	252	44	226	90	71	68	119
73695	I R BORDAG ES	24	1/21/1959	30.21441	-93.3076	P&A Oil Producer	8004	80	100	57	115	39	82	86
81563	I R BORDAG ES	26	10/3/1960	30.21261	-93.2955	P&A Dry Hole	7000	50	27	417	35	304	37	284
99914	PHOENIX DEV CO	1	11/20/196 3	30.1972	-93.2944	P&A Dry Hole	6013	93	97	61	97	61	30	368
102335	MATHILD A MILLER	61	4/26/1964	30.20541	-93.2898	Shut-in Producti ve Wells--Future Utility (Oil)	5900	106	46	213	95	64	96	62
135609	OLIN MATHIES ON CHEM CORP	1	12/14/197 0	30.2146	-93.2772	Wells Unable To Be Located	3452	148	75	101	92	68	80	90
147986	VUA;OLI N CORPORA TION	1	2/12/1975	30.209	-93.2752	Orphan Wells (Oil)	4955	82	70	114	63	135	58	153
147990	VUA;OLI N CORPORA TION	5	2/12/1975	30.21211	-93.2765	Orphan Wells (Oil)	4512	89	66	125	72	109	58	153

Table 1. Well Details and Chloride Data from Oil and Gas Wells.

Well Serial Number	Well Name	Well #	Permit Date	Surface Latitude (Nad83)	Surface Longitude (Nad83)	Well Status	Measured Depth (feet)	Beginning of Logged Interval (depth in feet)	200' sand Resist. (ohm-meters)	200' Cl^- (mg/L)	500' sand Resist. (ohm-meters)	500' Cl^- (mg/L)	700' sand Resist. (ohm-meters)	700' Cl^- (mg/L)
147989	VUA;OLIN CORPORATION	4	2/12/1975	30.2113	-93.276	Orphan Wells (Oil)	4500	96	63	135	62.5	137	60	146
151746	VUA;SL 6379	1	4/12/1976	30.21191	-93.2765	Orphan Wells (Oil)	4138	104	45	220	47	207	35	304
189414	ROBERT M MOSS ET AL	1	12/4/1983	30.20507	-93.3057	P&A Oil Producer	7995	108	43	233	100	57	100	57
210285	A 8 RA SUA;FARQUHAR	20	7/17/1989	30.20444	-93.2954	PA-35 Temporary Inactive Well	7219	200	71	111	61	142	50	190

Table 2. Well Details and Chloride Data from LADOTD Wells.

Well Number	**Latitude (NAD27)**	**Longitude (NAD27)**	**Year of Log**	**Screened Layer**	**200' resistivity**	**200' chloride**	**500' resistivity**	**500' chloride**	**700' resistivity**	**700' chloride**
Cu-731	30.21631718	-93.29015478	1962	700'	100	57	82	86	---	---
Cu-737	30.22103925	-93.28209912	1962	700'	70	114	101	55	98	59
Cu-746	30.21687272	-93.27126561	1962	700'	110	45	125	30	96	62
Cu-769	30.22666667	-93.30833333	1963	700'	78	94	115	39	---	---
Cu-782	30.20520642	-93.29959933	1964	700'	100	57	90	71	---	---
Cu-842	30.19687335	-93.32571082	1972	500'	68	119	90	71	---	---
Cu-848	30.17881837	-93.33793319	1972	500'	140	19	90	71	---	---
Cu-849	30.20159542	-93.30709944	1972	500'	98	59	81	88	---	---
Cu-850	30.20020658	-93.32209966	1972	500'	70	114	86	78	---	---
Cu-851	30.20361111	-93.32138889	1973	500'	146	15	117	37	---	---
Cu-852	30.19826219	-93.32265522	1973	500'	74	104	123	32	---	---
Cu-957	30.18909582	-93.3195996	1973	500'	100	57	---	---	---	---
Cu-810	30.23548325	-93.24793199	1974	700'	57	157	118	36	---	---
Cu-950	30.22742793	-93.29904382	1974	500'	100	57	---	---	---	---
Cu-951	30.22465024	-93.2993216	1974	500'	90	71	---	---	---	---
Cu-976	30.20937295	-93.30848836	1974	500'	89	73	63	135	---	---
Cu-1023	30.22548355	-93.27987687	1977	700'	87	77	90	71	---	---
Cu-1056	30.23520546	-93.2645989	1980	500'	106	49	---	---	---	---
Cu-1057	30.23492769	-93.2601544	1980	500'	114	40	---	---	---	---
Cu-1097	30.19270681	-93.32626637	1981	500'	112	42	118	36	---	---
Cu-1240	30.19187351	-93.30182156	1969	500'	58	153	98	59	---	---
Cu-1272	30.24437184	-93.25126541	1986	500'	50	190	---	---	---	---
Cu-1364	30.24492737	-93.25709883	1993	500'	91	70	---	---	---	---
Cu-1372	30.19770666	-93.32821085	1994	500'	77	97	80	90	69	117

Note:

Resistivity values in ohm-meters.

Chloride values in milligrams per liter

Table 3. Water Quality Data from USGS Wells

USGS ID	Local No.	Latitude (NAD27)	Longitude (NAD27)	Screened Layer	1940s average chloride (mg/L)	1950s average chloride (mg/L)	1940-50s average chloride (mg/L)	1960s average chloride (mg/L)	1970s average chloride (mg/L)	1960-70s average chloride (mg/L)	1980s average chloride (mg/L)	1990s average chloride (mg/L)	1980-90s average chloride (mg/L)
USGS 301416093150301	Cu- 9	30.23798315	-93.25098761	200'	39	---	39	---	---	---	---	---	---
USGS 301429093145501	Cu- 72	30.24159416	-93.24876536	200'	---	---	---	480	---	480	---	---	---
USGS 301434093163101	Cu- 88	30.24298299	-93.27543241	200'	---	21.4	21.4	---	---	---	---	---	---
USGS 301438093160901	Cu- 90	30.24409407	-93.26932122	200'	28	---	28	41	---	41	---	---	---
USGS 301516093143101	Cu- 112	30.25464939	-93.24209868	200'	---	---	---	32	---	32	---	---	---
USGS 301042093154801	Cu- 270	30.17854061	-93.26348761	200'	---	22	22	---	---	---	---	---	---
USGS 301430093162401	Cu- 561	30.24187192	-93.27348794	200'	---	36	36	38	---	38	---	---	---
USGS 301355093152301	Cu- 622	30.23215001	-93.25654323	200'	---	---	---	33.7	---	33.7	44	42	43
USGS 301404093170505	Cu- 729	30.23464993	-93.28487697	200'	---	---	---	18	---	18	---	---	---
USGS 301405093171006	Cu- 730	30.23492769	-93.28626588	200'	---	---	---	17	19.5	18.25	---	---	---
USGS 301258093172403	Cu- 733	30.21631718	-93.29015478	200'	---	---	---	15	---	15	---	---	---
USGS 301253093172302	Cu- 736	30.21492833	-93.28987699	200'	---	---	---	79	---	79	---	---	---
USGS 301315093165503	Cu- 739	30.22103925	-93.28209912	200'	---	---	---	17	25	21	---	---	---
USGS 301314093165905	Cu- 744	30.22076148	-93.28321024	200'	---	---	---	18.5	---	18.5	---	---	---
USGS 301300093161603	Cu- 748	30.21687272	-93.27126561	200'	---	---	---	---	25	25	---	27	27
USGS 301336093183002	Cu- 771	30.2268724	-93.3084884	200'	---	---	---	17.5	17.2	17.35	17	16.6	16.8
USGS 301148093193202	Cu- 843	30.19687335	-93.32571082	200'	---	---	---	---	98.4	98.4	50.3	17	33.65
USGS 301330093181701	Cu- 861	30.22520578	-93.30487723	200'	---	---	---	34	25.2	29.6	17.4	---	17.4
USGS 301350093171201	Cu- 866	30.23076116	-93.28682143	200'	---	---	---	---	---	---	---	18	18
USGS 301147093141901	Cu- 967	30.19659563	-93.23876508	200'	---	---	---	---	17.5	17.5	---	18	18
USGS 301341093174801	Cu- 987	30.22826124	-93.29682157	200'	---	---	---	---	19	19	18	18	18
USGS 301329093171402	Cu-1059	30.22492801	-93.28737698	200'	---	---	---	---	---	---	17	---	17
USGS 301339093173101	Cu-1060	30.2277057	-93.29209928	200'	---	---	---	---	---	---	18	17	17.5
USGS 301347093170501	Cu-1091	30.22992785	-93.28487696	200'	---	---	---	---	---	---	---	17	17
USGS 301225093194501	Cu-1100	30.2071508	-93.329322	200'	---	---	---	---	---	---	19	---	19
USGS 301352093171402	Cu-1128	30.2313167	-93.287377	200'	---	---	---	---	---	---	---	20	20

Table 3. Water Quality Data from USGS Wells

USGS ID	Local No.	Latitude (NAD27)	Longitude (NAD27)	Screened Layer	1940s average chloride (mg/L)	1950s average chloride (mg/L)	1940-50s average chloride (mg/L)	1960s average chloride (mg/L)	1970s average chloride (mg/L)	1960-70s average chloride (mg/L)	1980s average chloride (mg/L)	1990s average chloride (mg/L)	1980-90s average chloride (mg/L)
USGS 301326093170701	Cu-1365	30.22409471	-93.28543251	200'	---	---	---	---	---	---	---	17	17
USGS 301344093170501	Cu-1384	30.22909455	-93.28487695	200'	---	---	---	---	---	---	---	17	17
USGS 301415093171901	Cu-6694Z	30.23770538	-93.28876592	200'	---	---	---	---	---	---	---	18	18
USGS 301205093181501	Cu- 22	30.20159542	-93.30432162	500'	---	---	---	1717.5	---	1717.5	---	---	---
USGS 301412093160801	Cu- 52	30.23687208	-93.26904342	500'	41	---	41	---	---	---	---	---	---
USGS 301107093200101	Cu- 74	30.18548482	-93.33376647	500'	22.7	24	23.35	25.5	24.8	25.15	25.5	24	24.75
USGS 301121093195801	Cu- 76	30.18937359	-93.33293313	500'	23.6	20	21.8	23	26.3	24.65	---	---	---
USGS 301400093155001	Cu- 78	30.23353885	-93.26404334	500'	42	---	42	---	---	---	---	---	---
USGS 301356093160201	Cu- 79	30.23242777	-93.26737671	500'	---	---	---	45	41	43	38.3	47	42.65
USGS 301354093155201	Cu- 80	30.23187224	-93.26459889	500'	---	---	---	42	44.3	43.15	47.5	52	49.75
USGS 301356093154201	Cu- 81	30.23242777	-93.26182108	500'	43	---	43	33	32.3	32.65	---	---	---
USGS 301359093162201	Cu- 82	30.23326108	-93.27293235	500'	41	---	41	---	54.7	54.7	40.3	---	40.3
USGS 301406093155201	Cu- 83	30.23520546	-93.2645989	500'	41.5	44	42.75	42	35.2	38.6	31.5	38	34.75
USGS 301301093151101	Cu- 85	30.21715049	-93.2532098	500'	32.5	---	32.5	32	---	32	---	---	---
USGS 301427093162101	Cu- 86	30.24103861	-93.27265459	500'	---	87.3	87.3	105	---	105	---	---	---
USGS 301434093162801	Cu- 89	30.24298299	-93.27459907	500'	---	44	44	43.7	---	43.7	---	---	---
USGS 301438093160902	Cu- 90A	30.24409407	-93.26932122	500'	---	---	---	78.9	53.8	66.35	34.7	63	48.85
USGS 301438093160201	Cu- 91	30.24409407	-93.26737675	500'	50	44	47	---	---	---	---	---	---
USGS 301046093191201	Cu- 94	30.17965168	-93.32015514	500'	---	---	---	---	---	---	---	---	---
USGS 301110093193701	Cu- 97	30.18631813	-93.32709971	500'	22	21	21.5	---	---	---	---	---	---
USGS 301115093191501	Cu- 445	30.18770697	-93.32098851	500'	---	---	---	---	28.3	28.3	---	---	---
USGS 301349093190401	Cu- 447	30.23048339	-93.31793299	500'	---	26	26	24.3	---	24.3	---	---	---
USGS 301411093160101	Cu- 449	30.23659431	-93.26709894	500'	---	---	---	55	49.8	52.4	35	---	35
USGS 301423093155101	Cu- 450	30.23992753	-93.26432114	500'	38	---	38	48.5	45.2	46.85	---	67	67
USGS 301029093192401	Cu- 454	30.1749296	-93.32348852	500'	---	---	---	---	39	39	---	---	---

Table 3. Water Quality Data from USGS Wells

USGS ID	Local No.	Latitude (NAD27)	Longitude (NAD27)	Screened Layer	1940s average chloride (mg/L)	1950s average chloride (mg/L)	1940-50s average chloride (mg/L)	1960s average chloride (mg/L)	1970s average chloride (mg/L)	1960-70s average chloride (mg/L)	1980s average chloride (mg/L)	1990s average chloride (mg/L)	1980-90s average chloride (mg/L)
USGS 301422093160601	Cu- 458	30.23964977	-93.26848786	500'	---	---	---	62.7	81.2	71.95	50.5	68	59.25
USGS 301422093163801	Cu- 459	30.23964977	-93.27737688	500'	---	---	---	104.7	72.1	88.4	---	---	---
USGS 301402093162601	Cu- 460	30.23409439	-93.27404348	500'	---	---	---	40	64.5	52.25	---	---	---
USGS 301109093193301	Cu- 461	30.18604036	-93.32598858	500'	---	---	---	30	43.7	36.85	---	---	---
USGS 301106093203202	Cu-463B	30.18520705	-93.34237771	500'	---	---	---	31.6	30.5	31.05	27	28	27.5
USGS 301129093202001	Cu- 464	30.19159574	-93.33904434	500'	---	---	---	30.5	24.6	27.55	23.8	23	23.4
USGS 301407093161701	Cu- 465	30.23548323	-93.27154345	500'	---	---	---	60	81.7	70.85	75.3	70	72.65
USGS 301450093150501	Cu- 486	30.24742729	-93.25348767	500'	40	---	40	32	31	31.5	---	---	---
USGS 301505093155001	Cu- 490	30.25159384	-93.26404342	500'	44	---	44	---	---	---	---	---	---
USGS 301026093164802	Cu- 538	30.1740963	-93.28015452	500'	---	---	---	22	---	22	---	---	---
USGS 301035093193401	Cu- 560	30.17659622	-93.32626634	500'	---	35	35	---	26.5	26.5	67.8	110	88.9
USGS 301405093153601	Cu- 576	30.23492769	-93.2601544	500'	---	---	---	57	50	53.5	---	---	---
USGS 301101093172401	Cu- 590	30.18381821	-93.2901547	500'	---	20	20	29.5	---	29.5	---	---	---
USGS 301118093195001	Cu- 591	30.18854028	-93.33071088	500'	---	---	---	22.7	28	25.35	---	52	52
USGS 301338093172801	Cu- 615	30.22742793	-93.29126593	500'	---	---	---	25.4	50.6	38	106.5	137.6	122.05
USGS 301118093193601	Cu- 617	30.18854028	-93.32682193	500'	---	---	---	25.7	76	50.85	---	---	---
USGS 301035093191101	Cu- 619	30.17659622	-93.31987736	500'	---	28	28	26.5	21.6	24.05	22	---	22
USGS 301044093195001	Cu- 620	30.17909614	-93.33071086	500'	---	97	97	---	---	---	---	---	---
USGS 301319093165501	Cu- 627	30.22215032	-93.28209912	500'	---	---	---	29.9	---	29.9	123	---	123
USGS 301353093162001	Cu- 649	30.23159447	-93.27237678	500'	---	---	---	68.3	32.3	50.3	26	---	26
USGS 301505093163101	Cu- 654	30.25159384	-93.27543246	500'	---	40	40	40.5	---	40.5	---	---	---
USGS 301129093193501	Cu- 660	30.19159574	-93.32654415	500'	---	---	---	74.3	139	106.65	53.5	---	53.5
USGS 301448093151201	Cu- 663	30.24687176	-93.25348767	500'	---	---	---	37.5	---	37.5	---	---	---
USGS 301115093203601	Cu- 664	30.18770697	-93.34348885	500'	---	---	---	33.1	30.3	31.7	23.2	21	22.1
USGS 301029093194401	Cu- 676	30.1749296	-93.32904416	500'	---	---	---	68	113.3	90.65	---	340	340

Table 3. Water Quality Data from USGS Wells

USGS ID	Local No.	Latitude (NAD27)	Longitude (NAD27)	Screened Layer	1940s average chloride (mg/L)	1950s average chloride (mg/L)	1940-50s average chloride (mg/L)	1960s average chloride (mg/L)	1970s average chloride (mg/L)	1960-70s average chloride (mg/L)	1980s average chloride (mg/L)	1990s average chloride (mg/L)	1980-90s average chloride (mg/L)
USGS 301445093162201	Cu- 677	30.24603845	-93.27293239	500'	---	---	---	72.7	56	64.35	53.5	---	53.5
USGS 301505093164801	Cu- 678	30.25159384	-93.28015475	500'	---	---	---	35	47.3	41.15	---	---	---
USGS 301125093195801	Cu- 686	30.19048466	-93.33293313	500'	---	---	---	23.5	23.3	23.4	24	---	24
USGS 301059093190301	Cu- 689	30.18326267	-93.31765511	500'	---	19	19	56.5	166.4	111.45	256.7	---	256.7
USGS 301144093193901	Cu- 690	30.19576227	-93.32765529	500'	---	---	---	44.7	41.5	43.1	44.7	---	44.7
USGS 301112093201601	Cu- 692	30.18687367	-93.3379332	500'	---	---	---	31.6	31.9	31.75	25	22	23.5
USGS 301044093195101	Cu- 694	30.17909614	-93.33098864	500'	---	---	---	220	302.5	261.25	373.3	370.3	371.8
USGS 301027093191501	Cu- 699	30.17437407	-93.32098848	500'	---	---	---	44	37.6	40.8	36.6	73	54.8
USGS 301329093194101	Cu- 704	30.22492801	-93.3282109	500'	---	---	---	24	---	24	---	---	---
USGS 301329093194002	Cu- 705	30.22437248	-93.32793312	500'	---	---	---	44	---	44	---	---	---
USGS 301344093212801	Cu- 706	30.22909455	-93.35793355	500'	---	---	---	19	---	19	---	---	---
USGS 301248093151301	Cu- 707	30.21353949	-93.25376535	500'	---	---	---	30.7	---	30.7	---	---	---
USGS 301327093170601	Cu- 709	30.22437248	-93.28515472	500'	---	---	---	71.8	111.6	91.7	---	---	---
USGS 301334093165101	Cu- 711	30.22631686	-93.280988	500'	---	---	---	58.5	42.2	50.35	---	---	---
USGS 301339093161202	Cu- 712	30.2277057	-93.27015452	500'	---	39	39	34.5	29.5	32	---	---	---
USGS 301404093170502	Cu- 726	30.23464993	-93.28487697	500'	---	---	---	37.3	80	58.65	---	---	---
USGS 301404093170504	Cu- 728	30.23464993	-93.28487697	500'	---	---	---	32.5	---	32.5	---	---	---
USGS 301258093172402	Cu- 732	30.21631718	-93.29015478	500'	---	---	---	47.7	34	40.85	---	---	---
USGS 301301093172301	Cu- 734	30.21715048	-93.289877	500'	---	---	---	24	---	24	---	---	---
USGS 301315093165502	Cu- 738	30.22103925	-93.28209912	500'	---	---	---	40.3	41	40.65	---	---	---
USGS 301314093165903	Cu- 742	30.22076148	-93.28321024	500'	---	---	---	28	---	28	---	---	---
USGS 301314093165904	Cu- 743	30.22076148	-93.28321024	500'	---	---	---	28.3	---	28.3	---	---	---
USGS 301300093161602	Cu- 747	30.21687272	-93.27126561	500'	---	---	---	29.5	26	27.75	---	23	23
USGS 301257093161802	Cu- 750	30.21603941	-93.27182118	500'	---	---	---	43	---	43	---	---	---
USGS 301134093192101	Cu- 753	30.19298458	-93.32265521	500'	---	---	---	27	170	98.5	---	---	---
USGS 301345093170501	Cu- 754	30.22937232	-93.28487696	500'	---	---	---	57	214.3	135.65	175	---	175

Table 3. Water Quality Data from USGS Wells

USGS ID	Local No.	Latitude (NAD27)	Longitude (NAD27)	Screened Layer	1940s average chloride (mg/L)	1950s average chloride (mg/L)	1940-50s average chloride (mg/L)	1960s average chloride (mg/L)	1970s average chloride (mg/L)	1960-70s average chloride (mg/L)	1980s average chloride (mg/L)	1990s average chloride (mg/L)	1980-90s average chloride (mg/L)
USGS 301452093163901	Cu- 756	30.24798283	-93.27765468	500'	---	---	---	47	47	47	48	62	55
USGS 301252093165703	Cu- 766	30.21465056	-93.28265466	500'	---	---	---	50.5	---	50.5	---	---	---
USGS 301336093183003	Cu- 770	30.2268724	-93.3084884	500'	---	---	---	40	26.2	33.1	---	36	36
USGS 301046093191202	Cu- 778	30.17965168	-93.32015514	500'	---	---	---	---	173.3	173.3	182.5	310	246.25
USGS 301438093221701	Cu- 779	30.24409407	-93.37154487	500'	---	---	---	19	---	19	---	18	18
USGS 301218093175803	Cu- 784	30.20520642	-93.29959933	500'	---	---	---	62	79.4	70.7	113.3	---	113.3
USGS 301134093191101	Cu- 827	30.19298458	-93.31987739	500'	---	---	---	---	94	94	146	110	128
USGS 301149093190801	Cu- 828	30.19715112	-93.31904405	500'	---	---	---	---	151.1	151.1	190	190	190
USGS 301508093171301	Cu- 830	30.25242715	-93.28709931	500'	---	---	---	---	34	34	30.7	---	30.7
USGS 301510093170001	Cu- 831	30.2529827	-93.28348816	500'	---	---	---	---	30.7	30.7	28	26	27
USGS 301500093165501	Cu- 832	30.25020498	-93.28209919	500'	---	---	---	---	35.7	35.7	---	---	---
USGS 301454093164301	Cu- 833	30.24631622	-93.26904344	500'	---	---	---	---	32.3	32.3	---	---	---
USGS 301444093164501	Cu- 834	30.24576068	-93.26904344	500'	---	---	---	---	39	39	35	---	35
USGS 301437093163401	Cu- 835	30.2438163	-93.27626576	500'	---	---	---	---	48.4	48.4	53	83	68
USGS 301339093170102	Cu- 840	30.2277057	-93.28376582	500'	---	---	---	---	68.8	68.8	83.5	110	96.75
USGS 301148093193201	Cu- 842	30.19687335	-93.32571082	500'	---	---	---	---	341.1	341.1	381.7	310	345.85
USGS 301148093193203	Cu- 844	30.19687335	-93.32571082	500'	---	---	---	---	19.2	19.2	18	---	18
USGS 301230093193202	Cu- 847	30.20853965	-93.32571084	500'	---	---	---	---	158	158	130	---	130
USGS 301043093201601	Cu- 848	30.17881837	-93.33793319	500'	---	---	---	---	234.5	234.5	302	---	302
USGS 301205093182501	Cu- 849	30.20159542	-93.30709944	500'	---	---	---	---	72	72	74	93	83.5
USGS 301200093191901	Cu- 850	30.20020658	-93.32209966	500'	---	---	---	---	403.2	403.2	412.9	---	412.9
USGS 301213093191701	Cu- 851	30.20361111	-93.32138889	500'	---	---	---	---	370	370	435.7	400	417.85
USGS 301153093192101	Cu- 852	30.19826219	-93.32265522	500'	---	---	---	---	286.2	286.2	317.1	---	317.1
USGS 301122093195401	Cu- 857	30.18965136	-93.33182201	500'	---	---	---	---	26	26	28.7	---	28.7
USGS 301052093194401	Cu- 860	30.18131829	-93.32904417	500'	---	---	---	---	66	66	67.5	---	67.5
USGS 301048093193401	Cu- 862	30.18020721	-93.32626635	500'	---	---	---	---	136.4	136.4	130	57	93.5

Table 3. Water Quality Data from USGS Wells

USGS ID	Local No.	Latitude (NAD27)	Longitude (NAD27)	Screened Layer	1940s average chloride (mg/L)	1950s average chloride (mg/L)	1940-50s average chloride (mg/L)	1960s average chloride (mg/L)	1970s average chloride (mg/L)	1960-70s average chloride (mg/L)	1980s average chloride (mg/L)	1990s average chloride (mg/L)	1980-90s average chloride (mg/L)
USGS 301108093192301	Cu- 863	30.18576259	-93.32321076	500'	---	---	---	---	33.5	33.5	79.5	---	79.5
USGS 301351093173001	Cu- 867	30.23103893	-93.2918215	500'	---	---	---	---	38.1	38.1	41.7	50	45.85
USGS 301340093174101	Cu- 868	30.22798347	-93.29487709	500'	---	---	---	---	45.6	45.6	50	65	57.5
USGS 301349093171501	Cu- 869	30.23048339	-93.28765478	500'	---	---	---	---	84.1	84.1	111.25	130	120.625
USGS 301334093175301	Cu- 949	30.22631686	-93.29821047	500'	---	---	---	---	103	103	123	---	123
USGS 301338093175601	Cu- 950	30.22742793	-93.29904382	500'	---	---	---	---	59.5	59.5	---	---	---
USGS 301328093175701	Cu- 951	30.22465024	-93.2993216	500'	---	---	---	---	68.5	68.5	68.5	38	53.25
USGS 301335093165201	Cu- 955	30.22659463	-93.28126579	500'	---	---	---	---	---	---	27	39	33
USGS 301120093191002	Cu- 957	30.18909582	-93.3195996	500'	---	---	---	---	98.8	98.8	107.6	63	85.3
USGS 301031093204902	Cu- 960	30.17548514	-93.34709999	500'	---	---	---	---	41.7	41.7	60	120	90
USGS 301129093183001	Cu- 976	30.20937295	-93.30848836	500'	---	---	---	---	283.8	283.8	301.7	---	301.7
USGS 301456093182401	Cu-1016	30.24909391	-93.30682175	500'	---	---	---	---	36	36	36.8	---	36.8
USGS 301435093154601	Cu-1021	30.24326076	-93.26293224	500'	---	---	---	---	31	31	28	24	26
USGS 301444093162901	Cu-1022	30.24576068	-93.27487686	500'	---	---	---	---	36	36	34	---	34
USGS 301404093170507	Cu-1040	30.23464993	-93.28487697	500'	---	---	---	---	31	31	31	---	31
USGS 301406093155202	Cu-1056	30.23520546	-93.2645989	500'	---	---	---	---	---	---	85.5	79	82.25
USGS 301405093153602	Cu-1057	30.23492769	-93.2601544	500'	---	---	---	---	---	---	44	---	44
USGS 301419093203501	Cu-1087	30.23881646	-93.34321114	500'	---	---	---	---	---	---	---	49	49
USGS 301133093193401	Cu-1097	30.19270681	-93.32626637	500'	---	---	---	---	---	---	---	76	76
USGS 301356093160101	Cu-1109	30.23242777	-93.26709893	500'	---	---	---	---	---	---	35	---	35
USGS 301130093180601	Cu-1240	30.19187351	-93.30182156	500'	---	---	---	---	---	---	---	50	50
USGS 301456093182002	Cu-1250	30.24909391	-93.30571063	500'	---	---	---	---	---	---	---	35	35
USGS 301439093150401	Cu-1272	30.24437184	-93.25126541	500'	---	---	---	---	---	---	---	36	36
USGS 301427093164601	Cu-1317	30.24103861	-93.27959913	500'	---	---	---	---	---	---	---	37	37
USGS 301441093152501	Cu-1364	30.24492737	-93.25709883	500'	---	---	---	---	---	---	---	42	42
USGS 301151093194101	Cu-1372	30.19770666	-93.32821085	500'	---	---	---	---	---	---	---	50	50

Table 3. Water Quality Data from USGS Wells

USGS ID	Local No.	Latitude (NAD27)	Longitude (NAD27)	Screened Layer	1940s average chloride (mg/L)	1950s average chloride (mg/L)	1940-50s average chloride (mg/L)	1960s average chloride (mg/L)	1970s average chloride (mg/L)	1960-70s average chloride (mg/L)	1980s average chloride (mg/L)	1990s average chloride (mg/L)	1980-90s average chloride (mg/L)
USGS 301324093170501	Cu-1385	30.22353917	-93.28487694	500'	---	---	---	---	---	---	---	140	140
USGS 301254093171801	Cu- 13	30.2152061	-93.28848808	700'	---	---	---	44	---	44	---	---	---
USGS 301408093180901	Cu- 56	30.235761	-93.302655	700'	30	---	30	---	---	---	---	---	---
USGS 301119093200101	Cu- 75	30.18881805	-93.33376648	700'	155	160	157.5	---	340	340	---	---	---
USGS 301300093151101	Cu- 84	30.21687272	-93.2532098	700'	---	34	34	---	---	---	---	---	---
USGS 301428093162701	Cu- 92	30.24131638	-93.27432128	700'	166.7	176.7	171.7	143.3	---	143.3	---	---	---
USGS 301104093193501	Cu- 96	30.18465152	-93.32654414	700'	225.5	---	225.5	---	---	---	---	---	---
USGS 301116093193601	Cu- 98	30.18798474	-93.32682193	700'	133.3	310	221.65	---	---	---	---	---	---
USGS 301328093165001	Cu- 99	30.22465024	-93.28071022	700'	81	120	100.5	77.9	74.6	76.25	---	---	---
USGS 301329093171401	Cu- 100	30.22492801	-93.28737698	700'	40	100	70	---	---	---	---	---	---
USGS 301321093165201	Cu- 101	30.22270586	-93.28126578	700'	100	---	100	---	---	---	---	---	---
USGS 301115093191001	Cu- 446	30.18770697	-93.3195996	700'	---	---	---	---	340	340	---	---	---
USGS 301104093201401	Cu- 462	30.18465151	-93.33737764	700'	---	---	---	---	26.3	26.3	---	---	---
USGS 301022093165803	Cu- 537	30.17298523	-93.28293234	700'	---	180	180	235	---	235	---	---	---
USGS 301339093170101	Cu- 556	30.2277057	-93.28376582	700'	---	240	240	271.9	---	271.9	---	---	---
USGS 301315093165301	Cu- 575	30.22103925	-93.28154355	700'	---	---	---	54.6	---	54.6	---	---	---
USGS 301321093165202	Cu- 583	30.22270586	-93.28126578	700'	---	71	71	74	75.3	74.65	75.5	120	97.75
USGS 301343093165201	Cu- 710	30.22881678	-93.28126579	700'	---	150	150	166.1	165	165.55	160	200	180
USGS 301404093170501	Cu- 725	30.23464993	-93.28487697	700'	---	---	---	134.8	185	159.9	65.5	---	65.5
USGS 301404093170503	Cu- 727	30.23464993	-93.28487697	700'	---	---	---	180	---	180	---	---	---
USGS 301258093172401	Cu- 731	30.21631718	-93.29015478	700'	---	---	---	38.2	30	34.1	---	---	---
USGS 301315093165501	Cu- 737	30.22103925	-93.28209912	700'	---	---	---	69	69	69	115	---	115
USGS 301314093165901	Cu- 740	30.22076148	-93.28321024	700'	---	---	---	96	---	96	---	---	---
USGS 301314093165902	Cu- 741	30.22076148	-93.28321024	700'	---	---	---	54	---	54	---	---	---
USGS 301300093161601	Cu- 746	30.21687272	-93.27126561	700'	---	---	---	40	46	43	---	57	57
USGS 301257093161801	Cu- 749	30.21603941	-93.27182118	700'	---	---	---	43	---	43	---	---	---

Table 3. Water Quality Data from USGS Wells

USGS ID	Local No.	Latitude (NAD27)	Longitude (NAD27)	Screened Layer	1940s average chloride (mg/L)	1950s average chloride (mg/L)	1940-50s average chloride (mg/L)	1960s average chloride (mg/L)	1970s average chloride (mg/L)	1960-70s average chloride (mg/L)	1980s average chloride (mg/L)	1990s average chloride (mg/L)	1980-90s average chloride (mg/L)
USGS 301252093165701	Cu- 760	30.21465056	-93.28265466	700'	---	---	---	225	---	225	---	---	---
USGS 301252093165702	Cu- 765	30.21465056	-93.28265466	700'	---	---	---	110	---	110	---	---	---
USGS 301336093183001	Cu- 769	30.22666667	-93.30833333	700'	---	---	---	236	213.3	224.65	185	145	165
USGS 301218093175801	Cu- 782	30.20520642	-93.29959933	700'	---	---	---	410	---	410	---	---	---
USGS 301218093175802	Cu- 783	30.20520642	-93.29959933	700'	---	---	---	50	---	50	---	---	---
USGS 301100093200001	Cu- 789	30.18354044	-93.33348869	700'	---	---	---	100.4	255	177.7	230	160	195
USGS 301407093145201	Cu- 810	30.23548325	-93.24793199	700'	---	---	---	---	61.7	61.7	---	---	---
USGS 301031093204901	Cu- 959	30.17527778	-93.34694444	700'	---	---	---	---	132	132	130	120	125
USGS 301331093164701	Cu-1023	30.22548355	-93.27987687	700'	---	---	---	---	150	150	146.7	220	183.35
USGS 301407093145202	Cu-1043	30.23548325	-93.24793199	700'	---	---	---	---	140	140	67	---	67
USGS 301410093193301	Cu-1048	30.23631654	-93.32598867	700'	---	---	---	---	47	47	49.8	---	49.8

Table 4. Well Details and TDS data from Spontaneous Potential Analysis

Well Serial Number	Well Name	Well No.	Permit Date	Surface Latitude (Nad83)	Surface Longitude (Nad83)	Well Status	Measured Depth (ft)	Beginning of Logged Interval (depth in ft)	1000-2000 ft. TDS	2000-3000 ft. TDS	3000-4000 ft. TDS	4000-5000 ft. TDS	5000-6000 ft. TDS	6000-7000 ft. TDS	7000-8000 ft. TDS
42483	LOCK MOORE & CO LTD LEASE	1	1/2/1951	30.21320403	-93.28905523	Orphan Well	6005	100	89881	55834	77774	92078	85920	---	---
42914	BORDAGES-LEMOINE	3	3/19/1951	30.2010045	-93.28645678	P&A Oil Producer	5815	190	21052	35825	55801	73430	71334	---	---
47378	C F HAMBURG	1	11/19/1952	30.20000468	-93.31385814	P&A Dry Hole	9466	217	20203	97801	130681	146129	150541	132184	---
50156	MATHILDA MILLER	46	10/18/1953	30.2084039	-93.2987574	Shut-in Productive Wells--Future Utility (Oil)	7364	156	39842	50821	73955	111209	134634	116317	142894
50999	E PAULINE HAFER #3 LSE	1	1/11/1954	30.20240485	-93.31975689	P&A Dry Hole	7500	218	---	99080	108676	116985	119471	117228	---
52931	I R BORDAGES	14	7/18/1954	30.21220514	-93.29705612	P&A Oil Producer	5503	177	28616	51550	77707	84590	89680	---	---
54290	FRED VINCENT	1	11/4/1954	30.20040572	-93.32375687	P&A Dry Hole	6282	90	75151	91617	96233	121121	92602	76640	---
59904	LORRAINE W WILLIAMS GAS UNIT 2	1	1/10/1956	30.21880429	-93.31515698	P&A Gas Condensate Producer	9830	119	11386	70493	90733	107400	129348	115643	108818
59903	SAM H JONES ET AL	1	1/10/1956	30.21870383	-93.32365739	P&A Gas Condensate Producer	10277	121	24179	85101	115591	133650	136991	112558	140257
60137	MAPLEWOOD HOUSING CORP	1	1/29/1956	30.22530417	-93.31945718	P&A Gas Condensate Producer	9933	122	22430	67503	102459	113125	120715	100324	125634
60195	FARQUHAR	19	1/30/1956	30.20160377	-93.30385664	Shut-in Productive Wells--Future Utility (Oil)	6807	169	11835	42949	74640	124724	146770	125631	---

60504	I R BORDAGES	18	2/27/1956	30.21870568	-93.30245684	P&A Oil Producer	10003	197	17048	87606	183323	207256	199817	197499	181377
61496	KEARNEY HEIRS ET AL GAS UNIT 9	1	5/17/1956	30.21360513	-93.319458	P&A Dry Hole	9806	110	22244	44647	47818	53541	58868	53038	49973
61495	CITIES SERV REFG CORP GAS U 7	1	5/17/1956	30.22690525	-93.30585568	P&A Dry Hole	9883	183	19199	99561	102871	131157	126435	119460	96363
62995	I R BORDAGES SWD	19	8/13/1984	30.21380361	-93.30125791	P&A Producer	6750	100	16492	55382	73747	82550	81187	76084	---

Notes:

ft feet
TDS Total Dissolved Solids

TDS values in parts per million (ppm)

VITA

Alexandria Marie Suding was born in Batesville, Indiana in 1989. She grew up in St. Peter's, Indiana and North Vernon, Indiana. Upon graduation from Jennings County High School in 2007, she attended the University of Notre Dame to study Environmental Geosciences. Alexandria graduated cum laude with a Bachelor of Science degree in May 2011. She then moved to Louisiana in order to attend Louisiana State University and pursue studies in groundwater hydrology under Dr. Carol Wicks. Alexandria plans graduate in August 2013 with a Master of Science degree in Geology. She then plans to begin a professional career in environmental consulting.